

US007260985B2

(12) **United States Patent**
Gilbert et al.

(10) **Patent No.:** **US 7,260,985 B2**
(45) **Date of Patent:** **Aug. 28, 2007**

(54) **FORMATION TESTER TOOL ASSEMBLY
AND METHODS OF USE**

(75) Inventors: **Gregory N. Gilbert**, Sugar Land, TX (US); **James E. Stone**, Porter, TX (US); **Malcolm Douglas McGregor**, The Woodlands, TX (US); **Christopher Anthony Maranuk**, Houston, TX (US); **Kristopher V. Sherrill**, Humble, TX (US)

3,356,137 A 12/1967 Raugust
3,530,933 A 9/1970 Whitten
3,565,169 A 2/1971 Bell
3,811,321 A 5/1974 Urbanosky
3,813,936 A 6/1974 Urbanosky et al.
3,858,445 A 1/1975 Urbanosky
3,859,850 A 1/1975 Whitten et al.
3,859,851 A 1/1975 Urbanosky
3,864,970 A 2/1975 Bell
3,924,463 A 12/1975 Urbanosky

(Continued)

(73) Assignee: **Halliburton Energy Services, Inc.**, Houston, TX (US)

FOREIGN PATENT DOCUMENTS

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 92 days.

EP 0697501 A2 2/1996

(Continued)

OTHER PUBLICATIONS

(21) Appl. No.: **11/133,712**

PCT International Search Report dated Nov. 10, 2005.

(Continued)

(22) Filed: **May 20, 2005**

Primary Examiner—Robert Raevis

(65) **Prior Publication Data**

(74) *Attorney, Agent, or Firm*—Conley Rose, P.C.

US 2005/0257630 A1 Nov. 24, 2005

(57) **ABSTRACT**

Related U.S. Application Data

(60) Provisional application No. 60/573,293, filed on May 21, 2004.

(51) **Int. Cl.**
E21B 49/10 (2006.01)

(52) **U.S. Cl.** **73/152.24**

(58) **Field of Classification Search** **73/152.24**
See application file for complete search history.

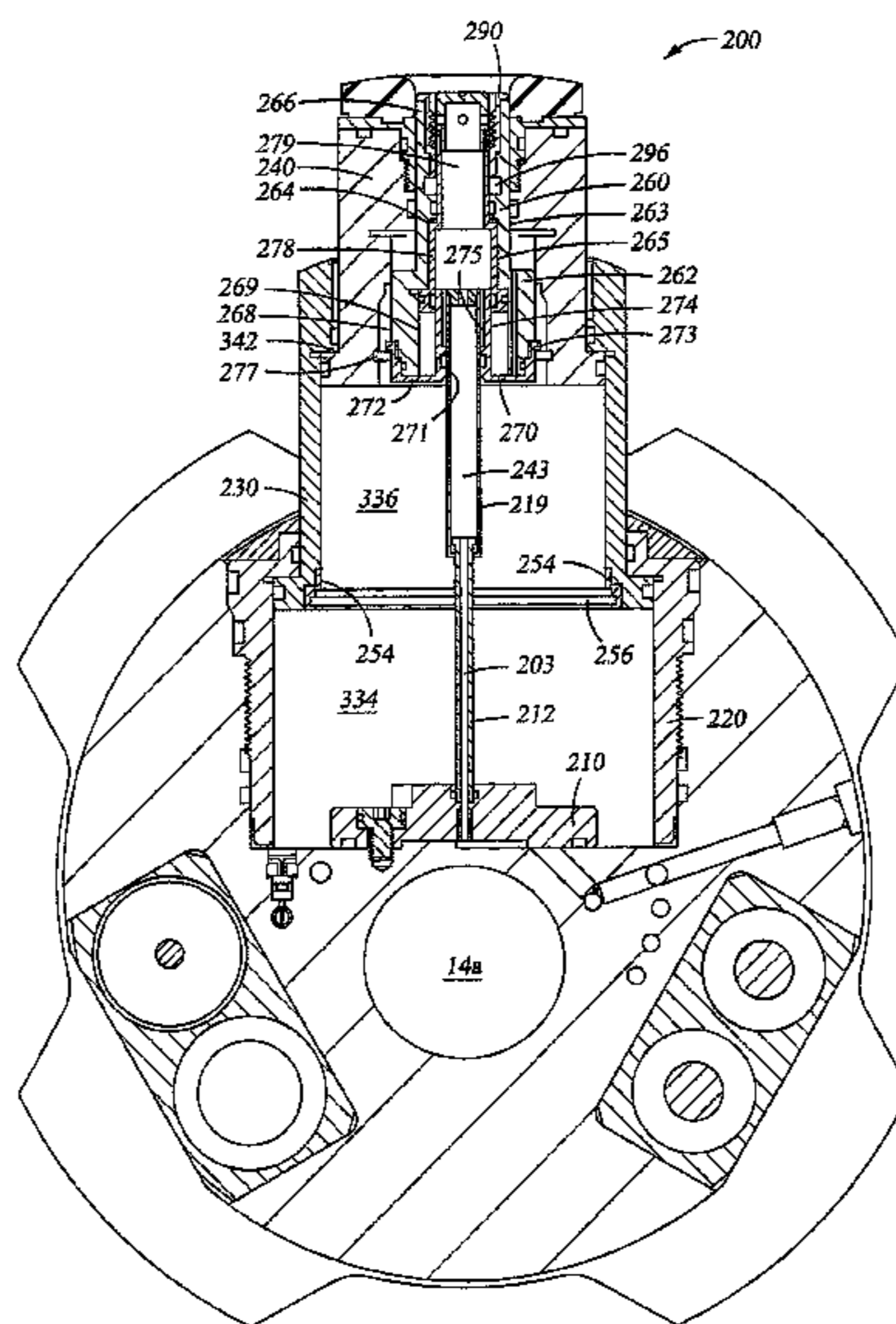
A downhole, extendable testing apparatus and methods of use are described and claimed herein. In one embodiment, an extendable sample device is connected to a draw down piston assembly. A position indicator may be used to show the position of the draw down piston during movement, and the draw down piston may be stopped and re-started, and moved at different rates. A filter may be used to clean fluids drawn into the extendable sample device. In another embodiment, the extendable sample device may connected to a hydraulic circuit. The hydraulic circuit may include accumulators for accumulating fluid pressures and operating the apparatus. Further apparatus and methods are disclosed herein.

(56) **References Cited**

U.S. PATENT DOCUMENTS

3,173,485 A 3/1965 Bretzke, Jr.
3,338,307 A 8/1967 Redwine

28 Claims, 19 Drawing Sheets



US 7,260,985 B2

U.S. PATENT DOCUMENTS					
			5,741,962 A	4/1998	Birchak et al.
			5,770,798 A	6/1998	Georgi et al.
			5,789,669 A	8/1998	Flaum
			5,803,186 A	9/1998	Berger et al.
			5,924,499 A	7/1999	Birchak et al.
			5,934,374 A	8/1999	Hrametz et al.
			5,969,241 A	10/1999	Auzerais
			6,026,915 A	2/2000	Smith et al.
			6,044,325 A	3/2000	Chakravarthy et al.
			6,047,239 A	4/2000	Berger et al.
			6,058,773 A	5/2000	Zimmerman et al.
			6,092,416 A	7/2000	Halford et al.
			6,109,370 A	8/2000	Gray
			6,111,409 A	8/2000	Edwards et al.
			6,128,949 A	10/2000	Kleinberg
			6,157,893 A	12/2000	Berger et al.
			6,164,126 A	12/2000	Ciglenec et al.
			6,178,815 B1	1/2001	Felling et al.
			6,223,822 B1	5/2001	Jones
			6,230,557 B1	5/2001	Ciglenec et al.
			6,247,542 B1	6/2001	Kruspe et al.
			6,274,865 B1	8/2001	Schroer et al.
			6,301,959 B1	10/2001	Hrametz et al.
			6,334,489 B1	1/2002	Shwe et al.
			6,343,507 B1	2/2002	Felling et al.
			6,350,986 B1	2/2002	Mullins et al.
			6,388,251 B1	5/2002	Papanyan
			6,415,648 B1	7/2002	Peeters
			6,427,530 B1	8/2002	Krueger et al.
			6,439,307 B1	8/2002	Reinhardt
			6,446,736 B1	9/2002	Kruspe et al.
			6,474,152 B1	11/2002	Mullins et al.
			6,476,384 B1	11/2002	Mullins et al.
			6,478,096 B1	11/2002	Jones et al.
			6,513,606 B1	2/2003	Krueger
			6,516,898 B1	2/2003	Krueger
			6,568,487 B2	5/2003	Meister et al.
			RE38,129 E	6/2003	Kleinberg
			6,581,455 B1	6/2003	Berger et al.
			6,585,045 B2	7/2003	Lee et al.
			6,609,568 B2	8/2003	Krueger et al.
			6,637,524 B2	10/2003	Kruspe et al.
			6,640,908 B2	11/2003	Jones et al.
			6,655,458 B2	12/2003	Kurkjian et al.
			6,658,930 B2	12/2003	Abbas
			6,659,177 B2	12/2003	Bolze et al.
			6,668,924 B2	12/2003	Bolze et al.
			6,672,386 B2	1/2004	Krueger et al.
			6,688,390 B2	2/2004	Bolze et al.
			6,719,049 B2	4/2004	Sherwood et al.
			6,729,399 B2	5/2004	Follini et al.
			6,745,835 B2	6/2004	Fields
			2001/0035289 A1	11/2001	Runia
			2002/0046835 A1	4/2002	Lee et al.
			2002/0060094 A1	5/2002	Meister et al.
			2002/0084072 A1	7/2002	Bolze et al.
			2002/0112854 A1	8/2002	Krueger et al.
			2002/0129936 A1	9/2002	Cernosek
			2002/0185313 A1	12/2002	Jones et al.
			2002/0189338 A1	12/2002	Kruspe et al.
			2002/0189339 A1	12/2002	Montalvo et al.
			2003/0042021 A1	3/2003	Bolze et al.
			2003/0062472 A1	4/2003	Mullins et al.
			2003/0066646 A1	4/2003	Shammai et al.
			2003/0098156 A1*	5/2003	Follini et al. 166/264
			2003/0146022 A1	8/2003	Krueger
			2003/0167834 A1	9/2003	Weintraub et al.
			2003/0214879 A1	11/2003	Proett et al.
			2003/0226663 A1	12/2003	Krueger et al.
			2004/0007058 A1	1/2004	Rylander et al.
			2004/0011525 A1*	1/2004	Jones et al. 166/264
			2004/0020649 A1	2/2004	Fields
			2004/0026125 A1	2/2004	Meister et al.

2004/0035199	A1	2/2004	Meister et al.	
2004/0045706	A1	3/2004	Pop et al.	
2004/0050153	A1	3/2004	Krueger et al.	
2004/0050588	A1	3/2004	Follini et al.	
2004/0099443	A1	5/2004	Meister et al.	
2004/0173351	A1	9/2004	Fox et al.	
2004/0230378	A1	11/2004	Proett et al.	
2004/0231408	A1	11/2004	Shammal	
2004/0231841	A1	11/2004	Niemeyer et al.	
2004/0231842	A1	11/2004	Shammai et al.	
2005/0082059	A1*	4/2005	Nogueira et al.	166/264
2005/0155760	A1*	7/2005	Hill et al.	166/264

FOREIGN PATENT DOCUMENTS

EP	0994238	A2	4/2000
EP	0978630	A2	9/2002
GB	2 304 906		3/1997
WO	WO 01/33044	A1	5/2001
WO	WO 01/33045	A1	5/2001
WO	WO 01/98630	A1	12/2001
WO	WO 02/08570	A1	1/2002

OTHER PUBLICATIONS

Joel L. Hebert; "A Method for Planning and Performing a Pressure Survey to Achieve Desired Accuracy of Pressure Gradient"; 2002 ASME Engineering Technology Conference on Energy; Feb. 4-5, 2002; pp. 1-8; ETCE 2002; American Society of Mechanical Engineers; Houston, Texas, U.S.A.

A.H. Akram et al.; "A Model to Predict Wireline Formation Tester Sample Contamination"; 1998 SPE Annual Technical Conference and Exhibition; Sep. 27-30, 1998; pp. 27-33; SPE 48959; Society of Petroleum Engineers, Inc.; New Orleans, Louisiana, U.S.A.

R. Desbrandes, et al.; "A New Concept in Wireline Formation Testing: Extended Drawdown," 13th CWLS Formation Evaluation Symp.; 1991; Calgary, Canada; pp. 1-25.

Yi Shaoguo et al.; "A New Flow Model of Pressure Response to Wireline Formation Testing"; Journal of Jiangnan Petroleum Institute; vol. 19, No. 3; Sep. 1997; pp. 42-45. (Partial translation attached).

E. Kasap; "A New, Simplified, Unified Technique For The Analysis of Wireline Formation Test Data"; SPWLA 37th Annual Logging Symposium; Jun. 16-19, 1996; pp. 1-13.

Kun Huang; "A Study of Dimensionless Parameters and Formation Rate Analysis Technique for Interpretation of WFT Data"; 1996; pp. 1-147; University of Tulsa; Tulsa, Oklahoma, U.S.A.

Mark A. Proett et al.; "Advanced Permeability and Anisotropy Measurements While Testing and Sampling in Real-Time Using a Dual Probe Formation Tester"; 2000 SPE Annual Technical Conference and Exhibition; Oct. 1-4, 2000; pp. 1-15; SPE 62919; Society of Petroleum Engineers, Inc.; Dallas, Texas, U.S.A.

Robert C. Earlougher, Jr.; "Advances In Well Test Analysis"; Society of Petroleum Engineers of AIME; 1997; New York, New York, U.S.A. and Dallas, Texas, U.S.A.

John Michaels et al.; "Advances in Wireline Formation Testing"; SPWLA 36th Annual Logging Symposium; Jun. 26-29, 1995; pp. 1-11.

Amit K. Sakar et al.; "Adverse Effects of Poor Mud Cake Quality: Supercharging and Fluid Sampling Study"; SPE Reservoir Eval. & Eng. 3 (3), Jun. 2000; pp. 256-262; Society of Petroleum Engineers, Inc.; U.S.A.

E. B. Dussan V. et al.; "An Analysis of the Pressure Response of a Single-Probe Formation Tester"; 62nd Annual Technical Conference and Exhibition; Sep. 27-30, 1987; pp. 519-527; SPE 16801; Society of Petroleum Engineers, Inc.; Dallas, Texas, U.S.A.

A.A. Grinko et al.; "Analysis of the Quality of Drilling-in of Producing Formation on the Basis of the Results of Tests During Drilling"; Stroit. Neft. Gaz. Skvazhin Sushe More; Apr.-May 1999; pp. 45-47; Nos. 4-5; ISSN 0130-3872; Russia.

Ekrem Kasa; "Analysis of Wireline Formation Test Data From Gas and Non-Darcy Flow Conditions"; 1998 SPE Permian Basin Oil and

Gas Recovery Conference; Mar. 25-27, 1998; pp. 183-189; SPE 39769; Society of Petroleum Engineers, Inc.; Midland, Texas, U.S.A.

T. Zimmerman et al.; "Application of Emerging Wireline Formation Testing Technologies"; Eighth Offshore South East Asia Conference; Dec. 4-7, 1990; pp. 83-95; OSEA 90105; Offshore South East Asia; Singapore.

M. Hooper et al.; "Applications for an LWD Formation Tester"; 1999 SPE European Formation Damage Conference; May 28-Jun. 1, 1999; pp. 1-8; SPE 52794; Society of Petroleum Engineers, Inc.; The Hague, The Netherlands.

Cosan Ayan et al.; "Characterizing Permeability with Formation Testers"; Oilfield Review, Autumn 2001; pp. 2-23.

H. Elshahawi et al.; "Correcting for Wettability and Capillary Pressure Effects on Formation Tester Measurements"; SPWLA 41st Annual Logging Symposium; Jun. 4-7, 2000; pp. 1-14; Society of Petroleum Well Log Analysts; Dallas, Texas, U.S.A.

H. Elshahawi et al.; "Correcting for Wettability and Capillary Pressure Effects on Formation Tester Measurements"; 2000 SPE Annual Technical Conference and Exhibition; Oct. 1-4, 2000; pp. 1-15; SPE 63075; Society of Petroleum Engineers, Inc.; Dallas, Texas, U.S.A.

M. D. Enikeev; "Effect of Shaft Curvature on The Results of Formation Testing During the Drilling of Sloping Wells"; May 1978; pp. 26-29; pub. No. 004224; All-Union Sci. Res. Inst of Pet & Geophys. Ind.; USSR. (Partial translation attached).

Jaedong Lee et al.; "Enhanced Wireline Formation Tests in Low-Permeability Formations: Quality Control Through Formation Rate Analysis"; 2000 SPE Rocky Mountain Regional/Low Permeability Reservoirs Symposium and Exhibition; Mar. 12-15, 2000; pp. 1-4 with Figures 1A-15; SPE 60392; Society of Petroleum Engineers Inc.; Denver, Colorado, U.S.A.

H. Badaam et al.; "Estimation of Formation Properties Using Multiprobe Formation Tester in Layered Reservoirs"; 1998 SPE Annual Technical Conference and Exhibition; Sep. 27-30, 1998; pp. 479-490; SPE 49141; Society of Petroleum Engineers, Inc.; New Orleans, Louisiana, U.S.A.

S.W. Burnie, "Estimation of Reservoir Productivity, Fluid Composition, and Reserves in Sour Gas Formations Using the MDT (Modular Formation Dynamics Tester) Tool and a Comparison with the Completed Well Performance"; 1st CSPG/CWLS Exploration, Evaluation & Exploitation Joint Symposium; May 26-31, 1995; 1 p (Abstract Only); Calgary, Canada.

I. Gaz et al.; "Exploring New Methodologies To Acquire DST Type Data"; 1997 Offshore Mediterranean Conference and Exhibition; Mar. 19-21, 1997; pp. 587-592; Ravenna, Italy.

R. Desbrandes et al.; "Field Applications of Wireline Formation Testers in Low-Permeability Gas Reservoirs"; 1991 SPE Gas Technology Symposium; Jan 23-25, 1991; pp. 223-236; SPE 21502; Society of Petroleum Engineers, Inc.; Houston, Texas, U.S.A.

Long Haitao; "Follow-Up Monitoring and Evaluation of the Formation Pressure in the Process of Drilling"; Natur. Gas Ind., vol. 20, No. 4, pp. 33-36; Jul. 25, 2000. (Partial translation attached).

M. Meister et al.; "Formation Pressure Testing During Drilling: Challenges and Benefits"; SPE Annual Technical Conference and Exhibition; Oct. 5-8, 2003; pp. 1-8; SPE 84088; Society of Petroleum Engineers, Inc.; Denver, CO, U.S.A.

Mark Proett et al.; "Formation Pressure Testing In The Dynamic Drilling Environment"; 2004 IADC/SPE Drilling Conference; Mar. 2-4, 2004; pp. 1-11; IADC/SPE 87090; Society of Petroleum Engineers, Inc.; Dallas, Texas, U.S.A.

C. Frimann-Dahl et al.; "Formation Testers vs DST—The Cost Effective Use of Transient Analysis to Get Reservoir Parameters"; 1998 SPE Annual Technical Conference; Sep. 27-30, 1998; pp. 1-14; SPE 48962; Society of Petroleum Engineers, Inc.; New Orleans, Louisiana, U.S.A.

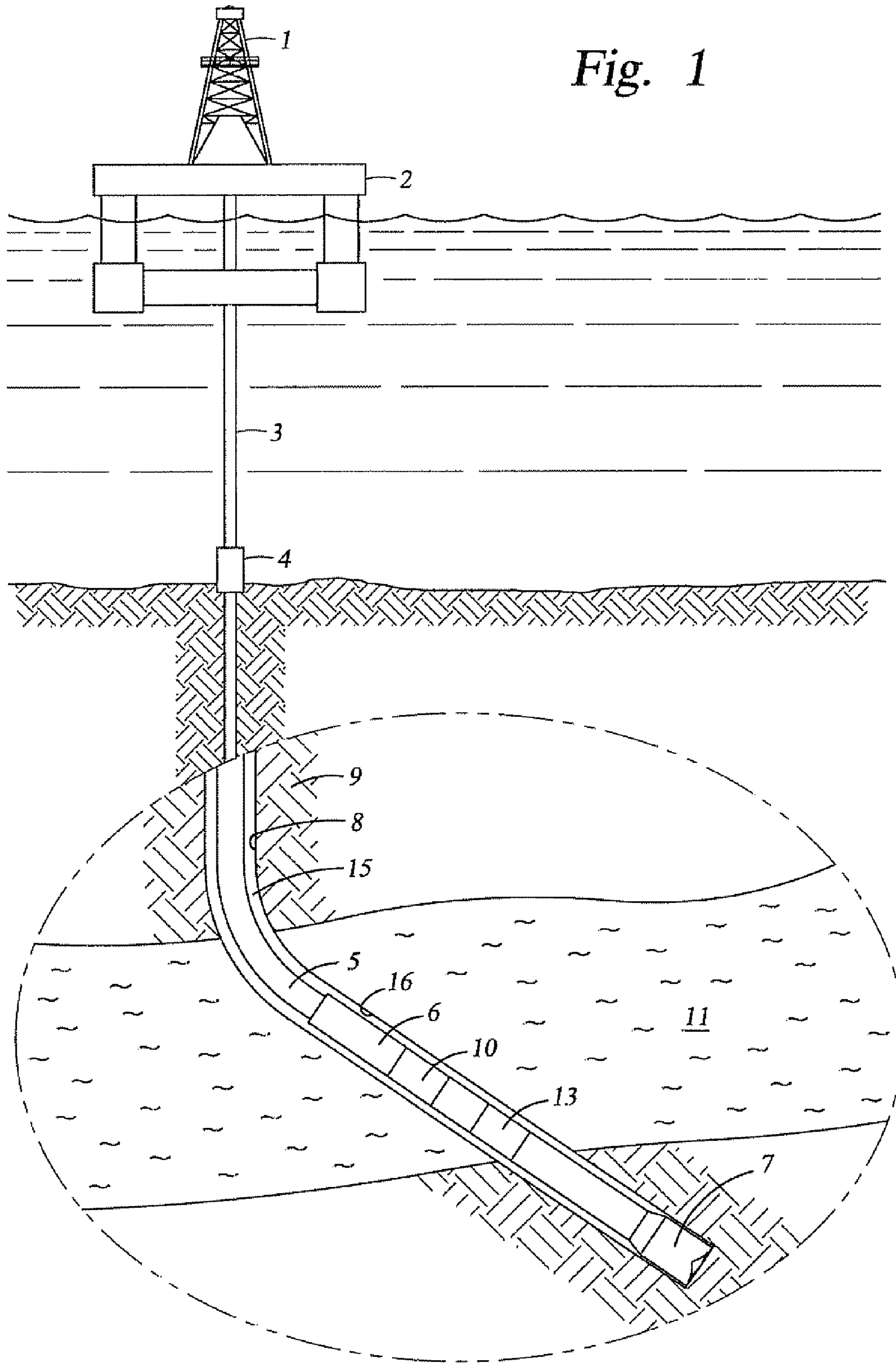
P.S. Varlamov et al.; "Formation Testing During Deep Well Drilling"; 1983; pp. 118-124; No. 39; Russia. (Partial translation attached).

Peter A. Goode et al.; "Influence of an Invaded Zone on a Multiprobe Formation Tester"; SPE Formation Evaluation, Mar. 1996; pp. 31-40.

- Alastair Crombie et al.; "Innovations in Wireline Fluid Sampling"; pp. 26-41; Oilfield Review, Autumn 1998.
- R. Desbrandes; "Invasion Diameter and Supercharging in Time-Lapse MWD/LWD Logging"; Proceedings, Measurement While Drilling Symposium; Feb. 26-27, 1990; pp. 115-135; Louisiana State University; Baton Rouge, Louisiana, U.S.A.
- Mark A. Proett et al.; "Low Permeability Interpretation Using a New Wireline Formation Tester 'Tight Zone' Pressure Transient Analysis"; 1994 SPWLA 35th Annual Logging Symposium; Jun. 19-22, 1994; pp. 1-25.
- R. Desbrandes et al.; "Measurement While Drilling"; Studies in Abnormal Pressures. Developments in Petroleum Science, 38; 1994; pp. 251-279; Elsevier Science B.V.
- Mark A. Proett et al.; "Multiple Factors That Influence Wireline Formation Tester Pressure Measurements and Fluid Contact Estimates"; 2001 SPE Annual Technical Conference and Exhibition; Sep. 30-Oct. 3, 2001; pp. 1-16; SPE 71566; Society of Petroleum Engineers, Inc.; New Orleans, Louisiana, U.S.A.
- Mark A. Proett et al.; "New Dual-Probe Wireline Formation Testing and Sampling Tool Enables Real-Time Permeability and Anisotropy Measurements"; 2000 SPE Permian Basin Oil and Gas Recovery Conference; Mar. 21-23, 2000; pp. 1-16; SPE 59701; Society of Petroleum Engineers, Inc.; Midland, Texas, U.S.A.
- Mark A. Proett et al.; "New Exact Spherical Flow Solution With Storage and Skin For Early-Time Interpretation With Applications to Wireline Formation and Early-Evaluation Drillstem Testing"; 1998 SPE Annual Technical Conference and Exhibition; Sep. 27-30, 1998; pp. 463-478; SPE 49140; Society of Petroleum Engineers, Inc.; New Orleans, Louisiana, U.S.A.
- Mark A. Proett et al.; "New Exact Spherical Flow Solution With Storage For Early-Time Interpretation With Applications to Early-Evaluation Drillstem Testing and Wireline Formation Testing"; 1998 SPE Permian Basin Oil and Gas Recovery Conference; Mar. 25-27, 1998; pp. 167-181; SPE 39768; Society of Petroleum Engineers, Inc.; Midland, Texas, U.S.A.
- Rob Badry et al.; "New Wireline Formation Tester Techniques and Applications"; 1993 SPWLA Annual Symposium; Jun. 13-16, 1993; pp. 1-15; Calgary, Alberta, Canada.
- Mark A. Proett et al.; "New Wireline Formation Testing Tool With Advanced Sampling Technology"; 1999 SPE Annual Technical Conference and Exhibition; Oct. 3-6, 1999; pp. 1-16, SPE 56711; Society of Petroleum Engineers, Inc.; Houston, Texas, U.S.A.
- A. F. Shakirov et al.; "On The Regimes of Formation Testing In Wells"; Neft Khoz; Dec. 1973; pp. 14-17; No. 12; RUSSIA.
- K. Zainun et al.; "Optimized Exploration Resource Evaluation Using the MDT Tool"; 1995 SPE Asia Pacific Oil and Gas Conference; Mar. 20-22, 1995; pp. 177-194; SPE 29270; Society of Petroleum Engineers, Inc.; Kuala Lumpur, Malaysia.
- Jaedong Lee et al.; "Pressure Test Analysis of Gas Bearing Formations"; 1998 SPWLA 39th Annual Logging Symposium; May 26-29, 1998; pp. 1-9.
- Mark A. Proett et al.; "Real Time Pressure Transient Analysis Methods Applied to Wireline Formation Test Data"; 69th Annual Technical Conference and Exhibition of the Society of Petroleum Engineers; Sep. 25-28, 1994; pp. 1-16; SPE 28449; Society of Petroleum Engineers, Inc.; New Orleans, Louisiana, U.S.A.
- V. D. Banchenko et al.; "Results of Using Strata Testers Mounted on Tubes Lowered Into Boreholes in the Southern Mangyshiak Field"; 1982; pp. 28-29; No. 8; ISSN- 0521-8136; Burenin; Russia (Partial translation attached).
- E. Kasap et al.; "Robust and Simple Graphical Solution For Wireline Formation Tests: Combined Drawdown and Buildup Analyses"; 1996 SPE Annual Technical Conference and Exhibition; Oct. 6-9, 1996; pp. 343-357; SPE 36525; Society of Petroleum Engineers, Inc.; Denver, Colorado, U.S.A.
- S. Haddad et al.; "So What Is The Reservoir Permeability?"; 2000 SPE Annual Technical Conference and Exhibition; Oct. 1-4, 2000; pp. 1-13; SPE 63138; Society of Petroleum Engineers, Inc.; Dallas, Texas, U.S.A.
- P. Cooke-Yarborough; "Some 'Quick-Look' and Wellsite Applications of Wireline Formation Testing Tools With Emphasis on Permeability Indicators as an Aid to Choosing Net Pay Discriminations"; Proceedings Indonesian Petroleum Association; Thirteenth Annual Convention; May 1994; pp. 1-16.
- P.S. Lapshin et al.; "Study of the Effect of Variable Inflow on Accuracy of Determining Formation Parameters with Formation Testers"; 1971; pp. 11-14; No. 1; Nefteprom. Delo; Russia. (Partial translation attached).
- Mark A. Proett et al.; "Supercharge Pressure Compensation Using a New Wireline Testing Method and Newly Developed Early Time Spherical Flow Model"; 1996 SPE Annual Technical Conference and Exhibition; Oct. 6-9, 1996; pp. 329-342; SPE 36524; Society of Petroleum Engineers, Inc.; Denver, Colorado, U.S.A.
- G.D. Phelps et al.; "The Analysis of the Invaded Zone Characteristics and Their Influence on Wireline Log and Well-Test Interpretation"; 1984 Society of Petroleum Engineers of AIME 59th Annual Conference and Exhibition; Sep. 16-19, 1984; pp. 1-10; Tables 1-4; Figures 1-14; SPE 13287; Society of Petroleum Engineers of AIME; Houston Texas, U.S.A.
- D.K. Sethi et al.; "The Formation Multi-Tester: Its Basic Principles and Practical Field Applications"; SPWLA Twenty-First Annual Logging Symposium; Jul. 8-11, 1980; pp. 1-34.
- M.M. Kamal et al.; "Use of Transient Testing in Reservoir Management"; University of Tulsa Centennial Petroleum Engineering Symposium; Aug. 29-31, 1994; pp. 519-531; SPE 28008; Society of Petroleum Engineers; Tulsa, Oklahoma, U.S.A.
- "Well Testing Using Wireline Methods"; Schlumberger East Asia Well Evaluation Conference; 1981; pp. 121-144; Singapore.
- R. Desbrandes et al.; "Wettability and Productivity Characterization of Low Permeability Gas Formations: Annual Report"; Gas Research Institute: Report GRI-91/0135; Mar. 6, 1991.
- T. M. Whittle et al.; "Will Wireline Formation Tests Replace Well Tests?"; 2003 SPE Annual Technical Conference and Exhibition; Oct. 5-8, 2003; pp. 57-58; SPE 84086; Society of Petroleum Engineers, Inc.; Denver, Colorado, U.S.A.
- J. Michaels et al.; "Wireline Fluid Sampling"; 1995 SPE Annual Technical Conference and Exhibition; Oct. 22-25, 2005; pp. 871-878; SPE 36010; Society of Petroleum Engineers, Inc.; Dallas, Texas, U.S.A.
- E. C. Thomas; "Wireline Formation Tester Data: Fact or Fiction?"; Petrophysics, vol. 41, No. 5, Sep.-Oct. 2000; pp. 357-378.
- R. Desbrandes; "Wireline Formation Testing: A New Extended Drawdown Technique"; Petroleum Engineer International; pp. 40-44; May 1991.

* cited by examiner

Fig. 1



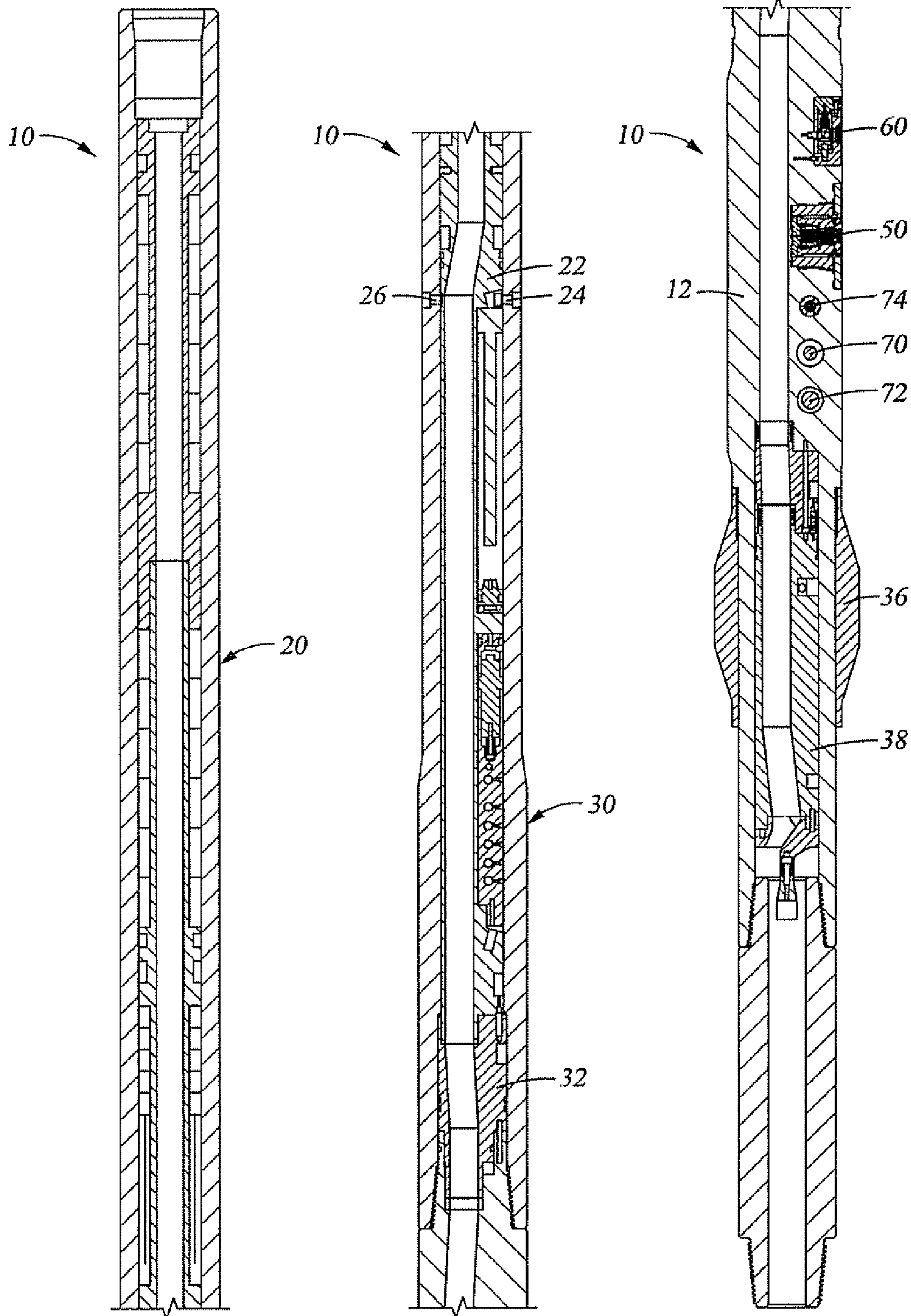


Fig. 2A

Fig. 2B

Fig. 2C

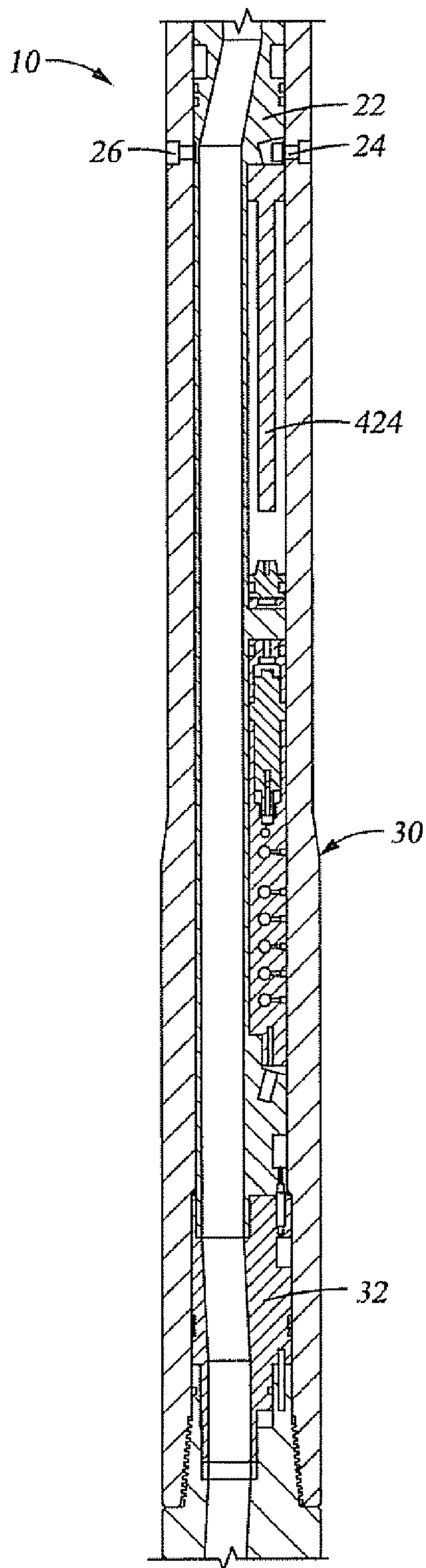


Fig. 3A

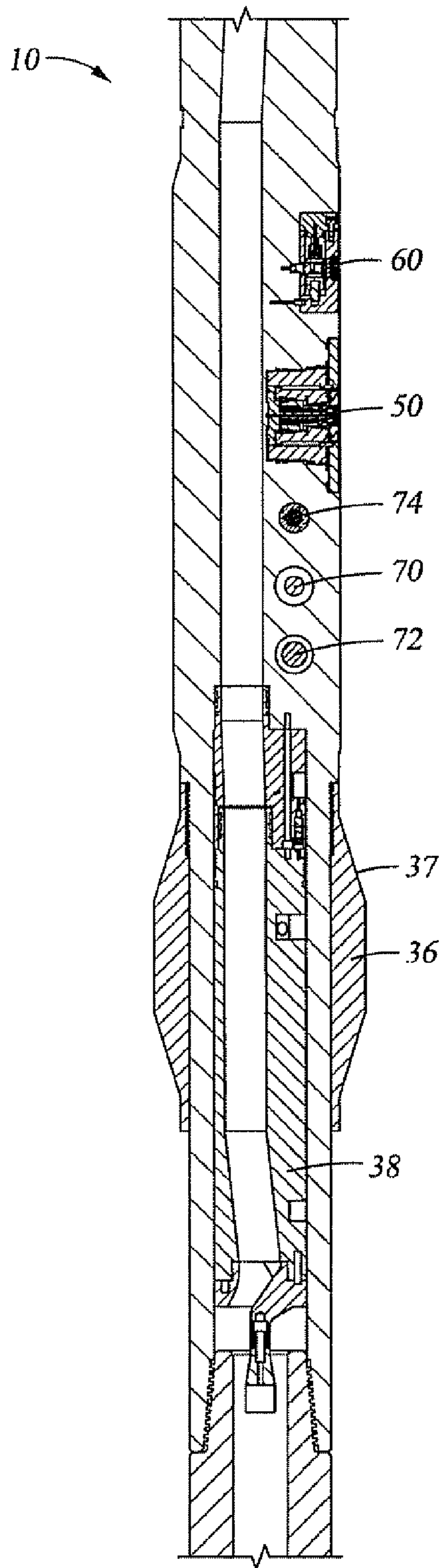


Fig. 3B

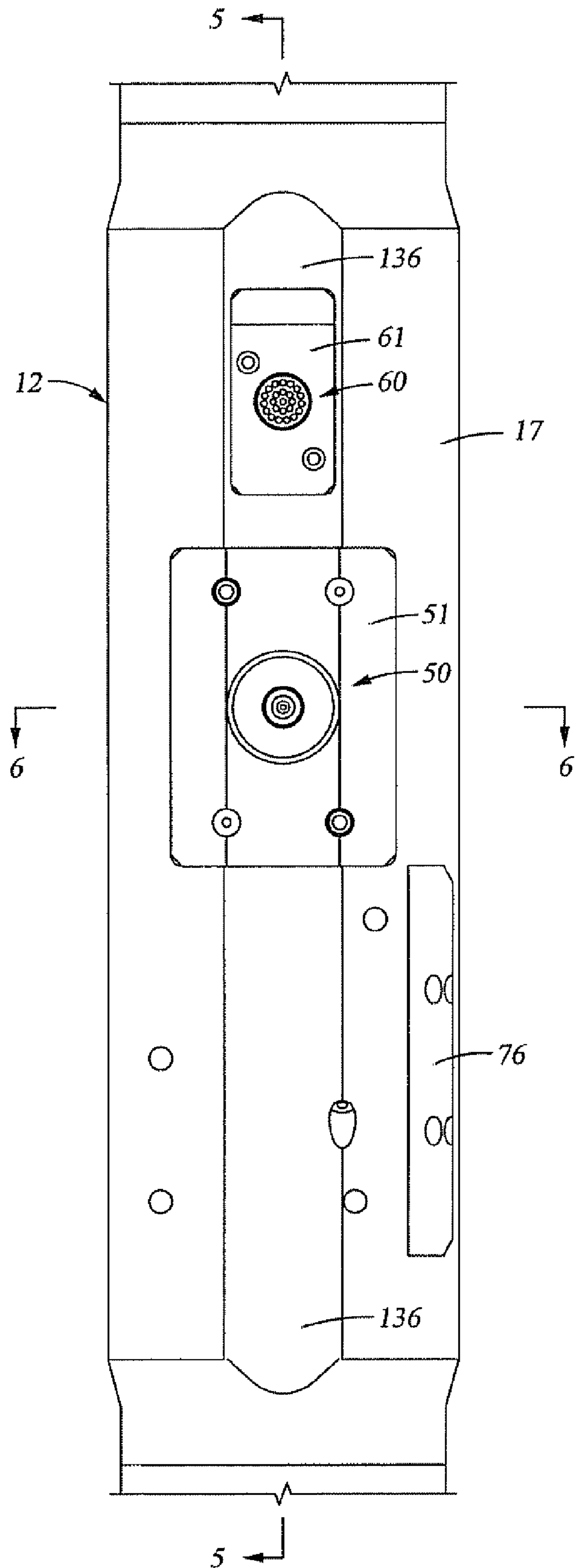


Fig. 4

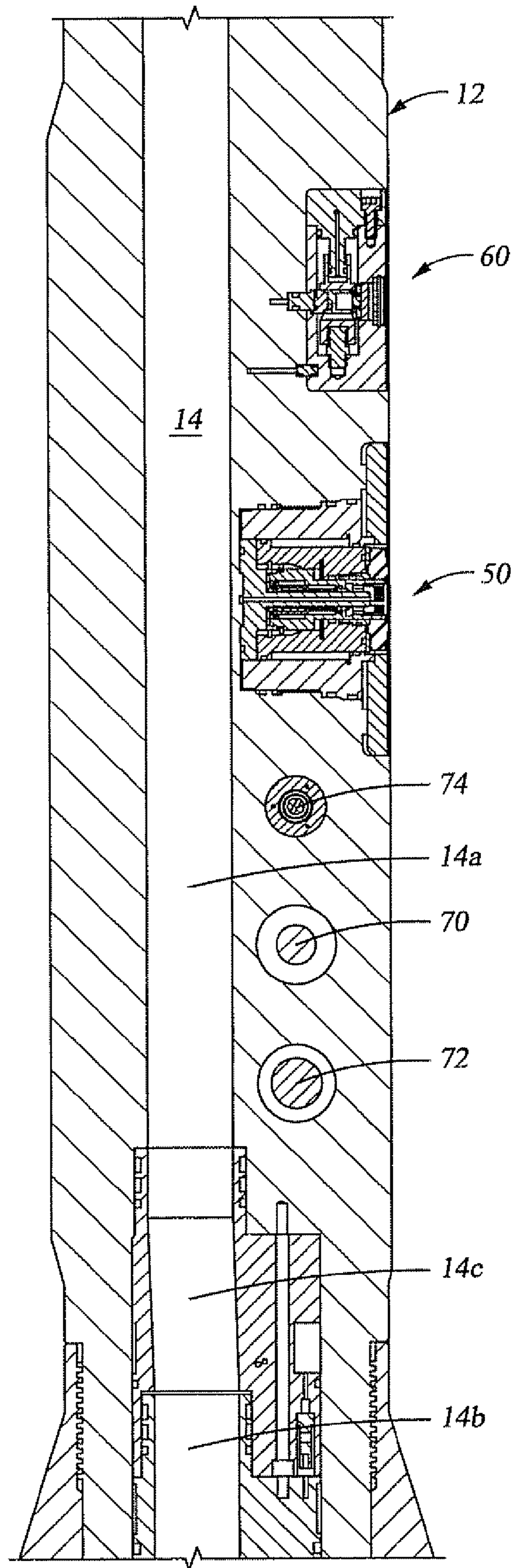


Fig. 5

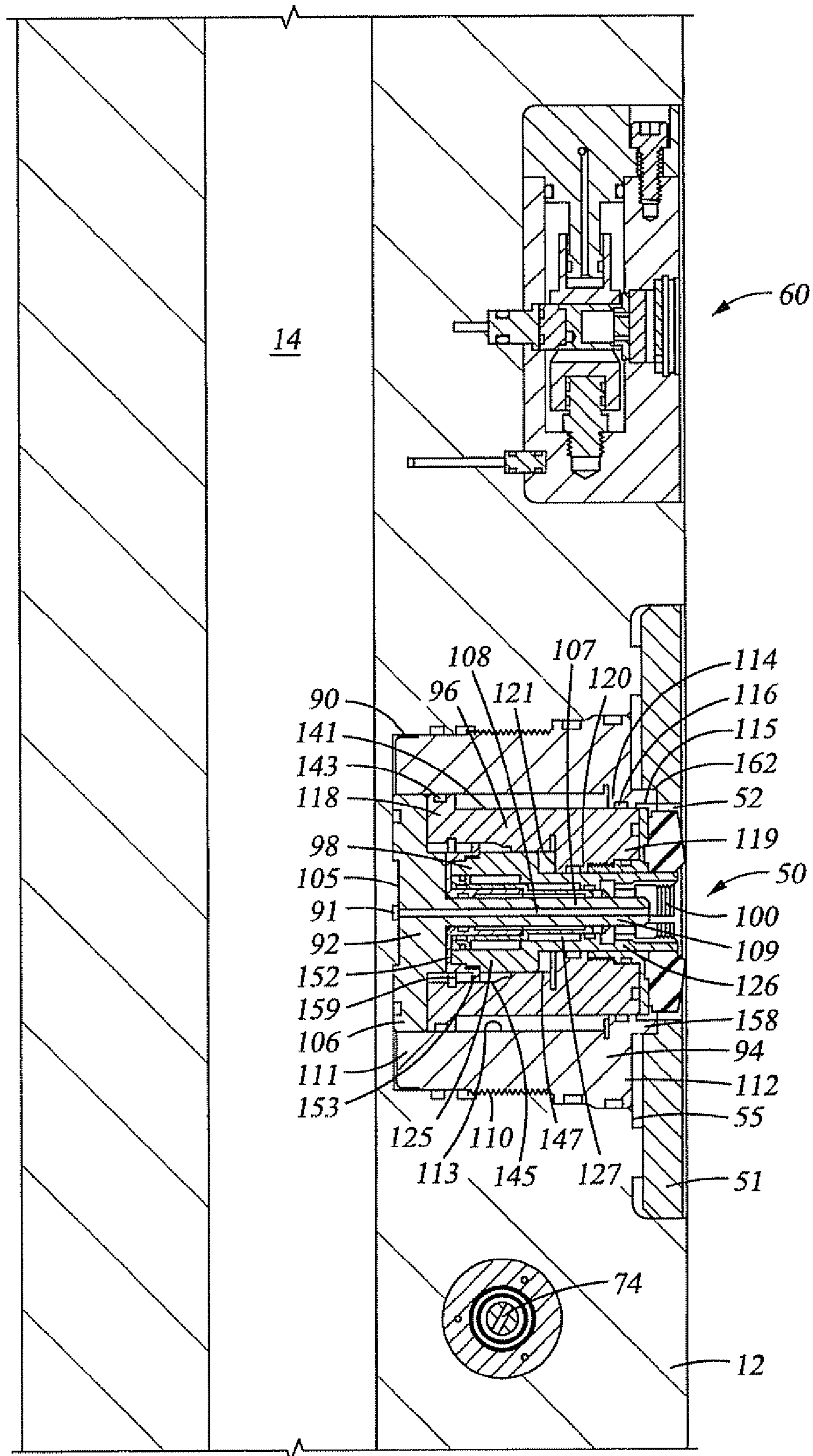


Fig. 6A

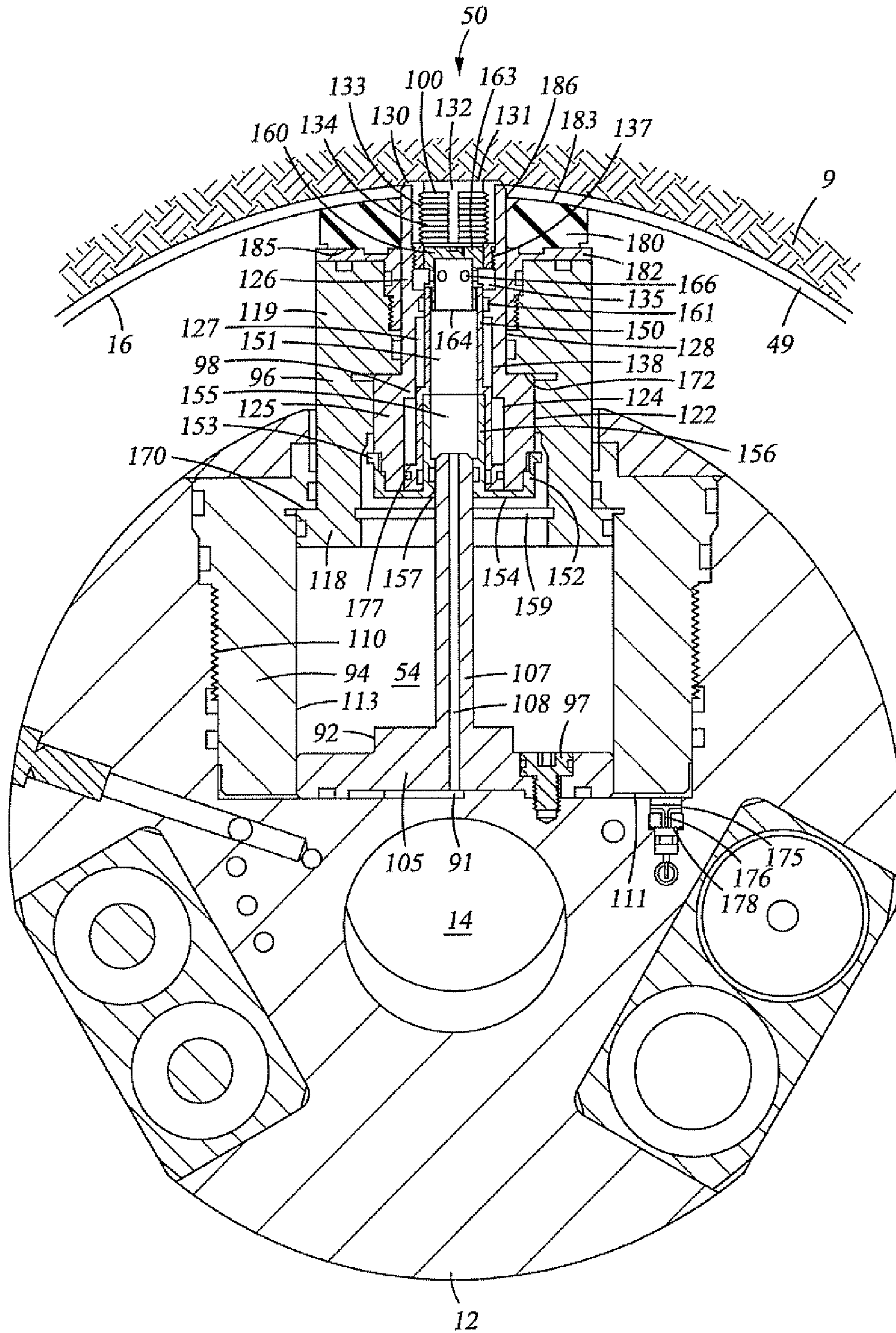


Fig. 6B

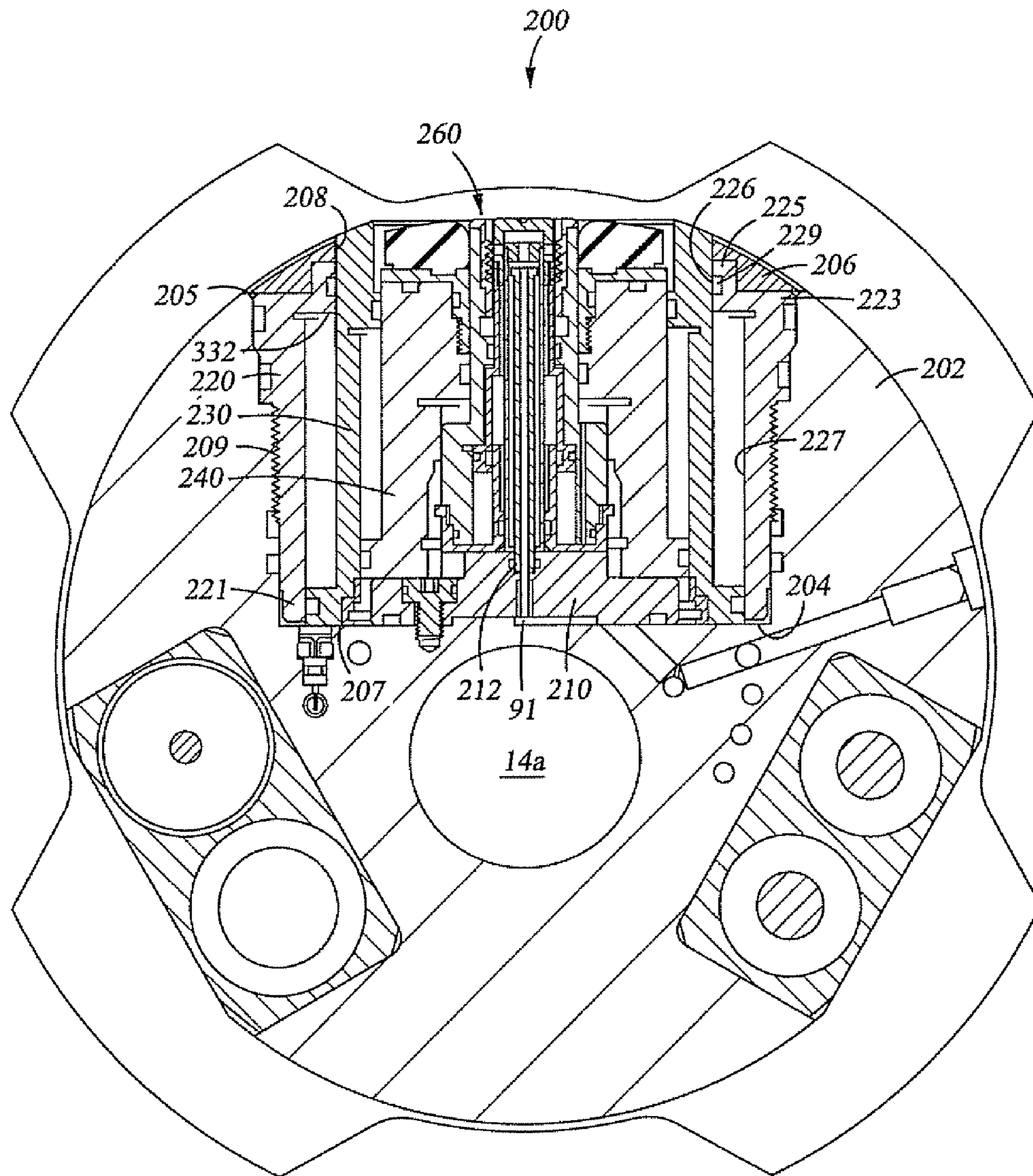


Fig. 7A

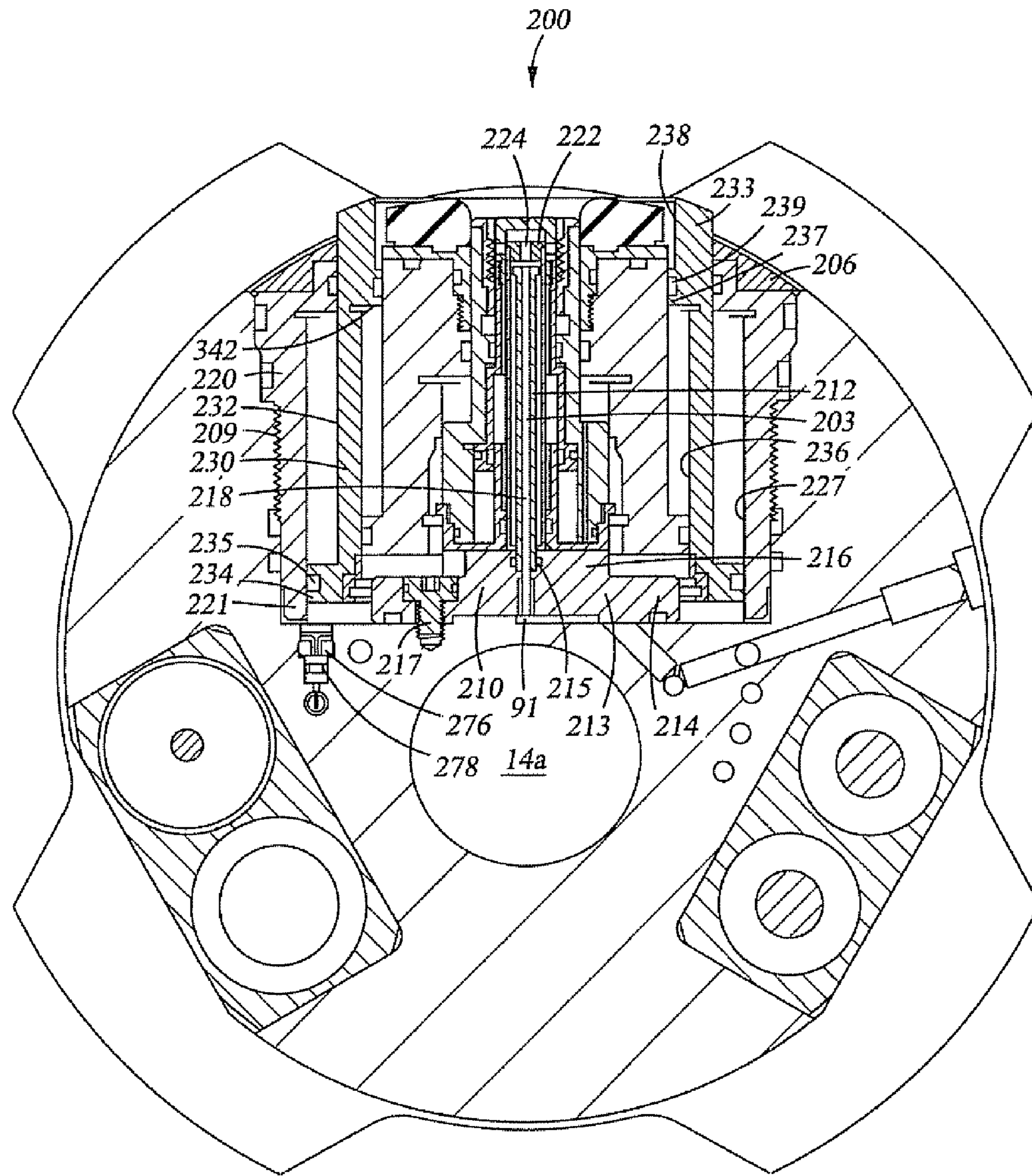


Fig. 7B

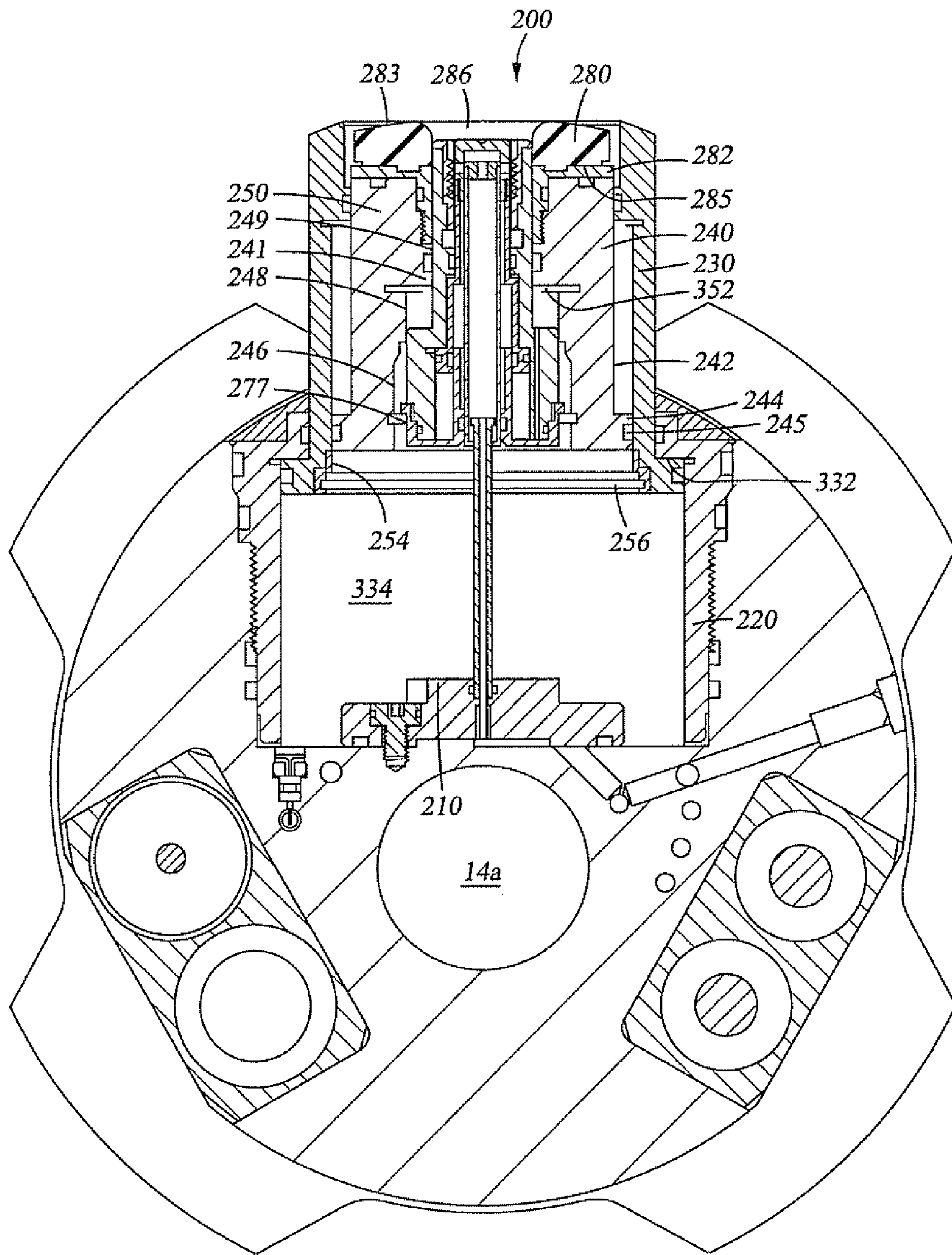


Fig. 7C

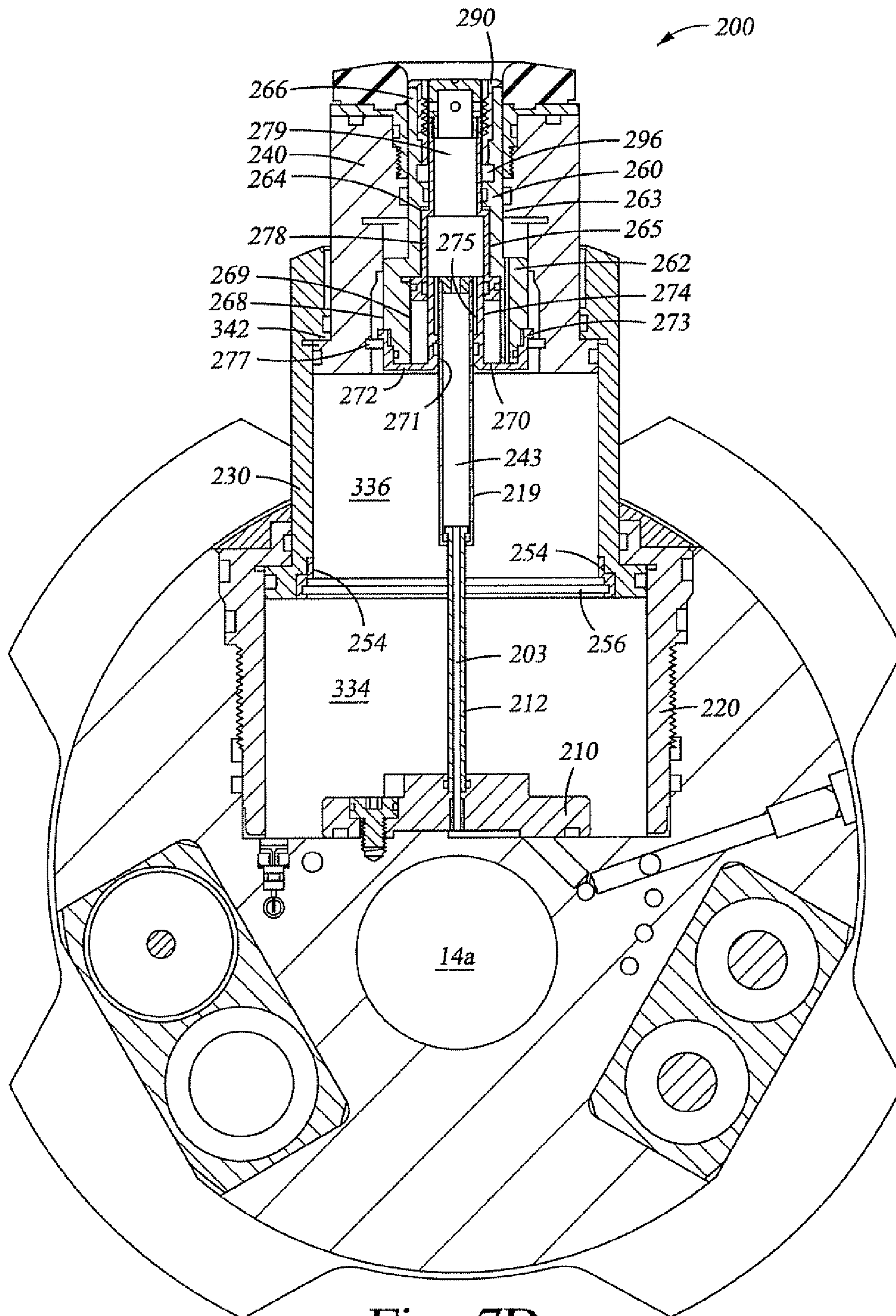


Fig. 7D

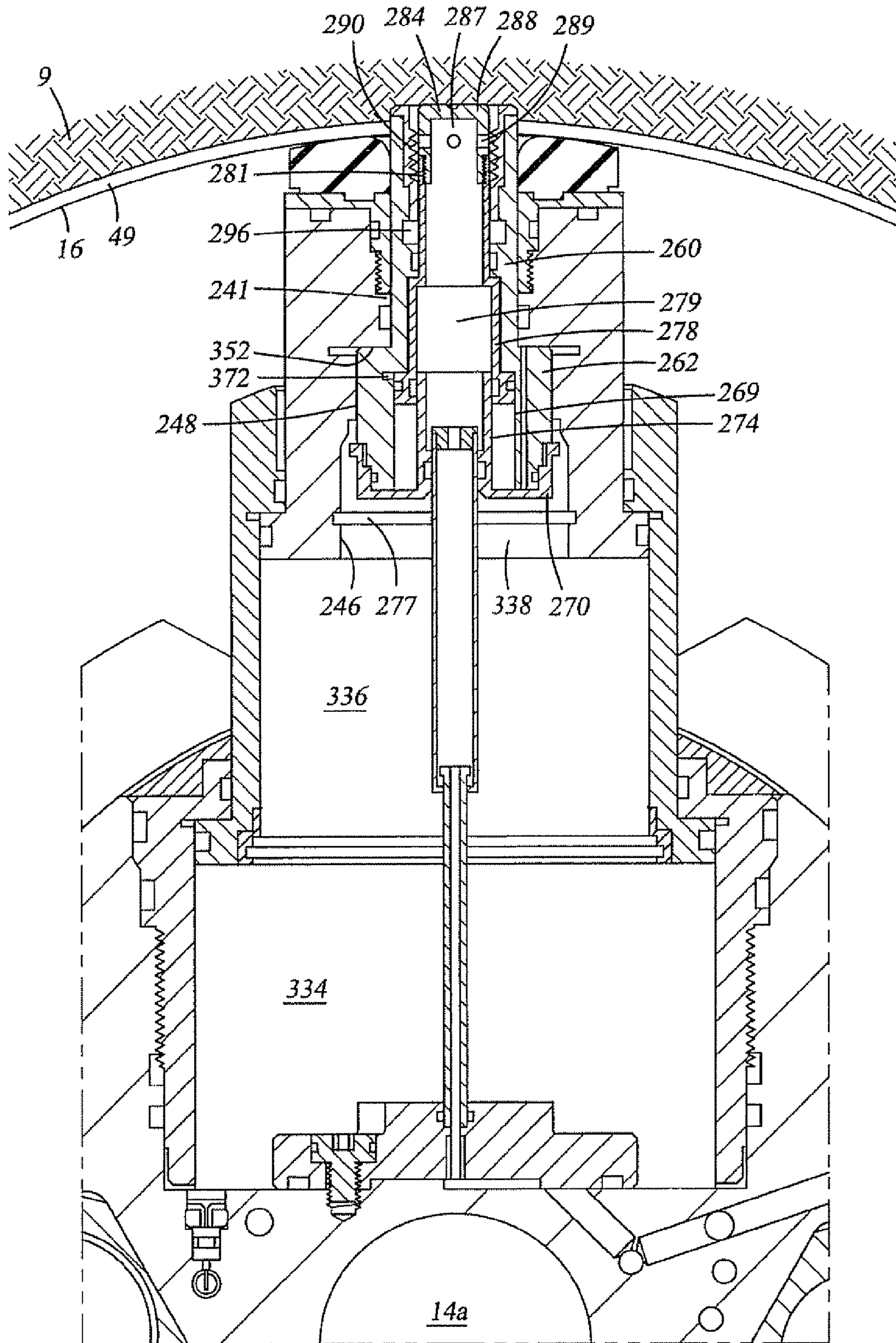


Fig. 7E

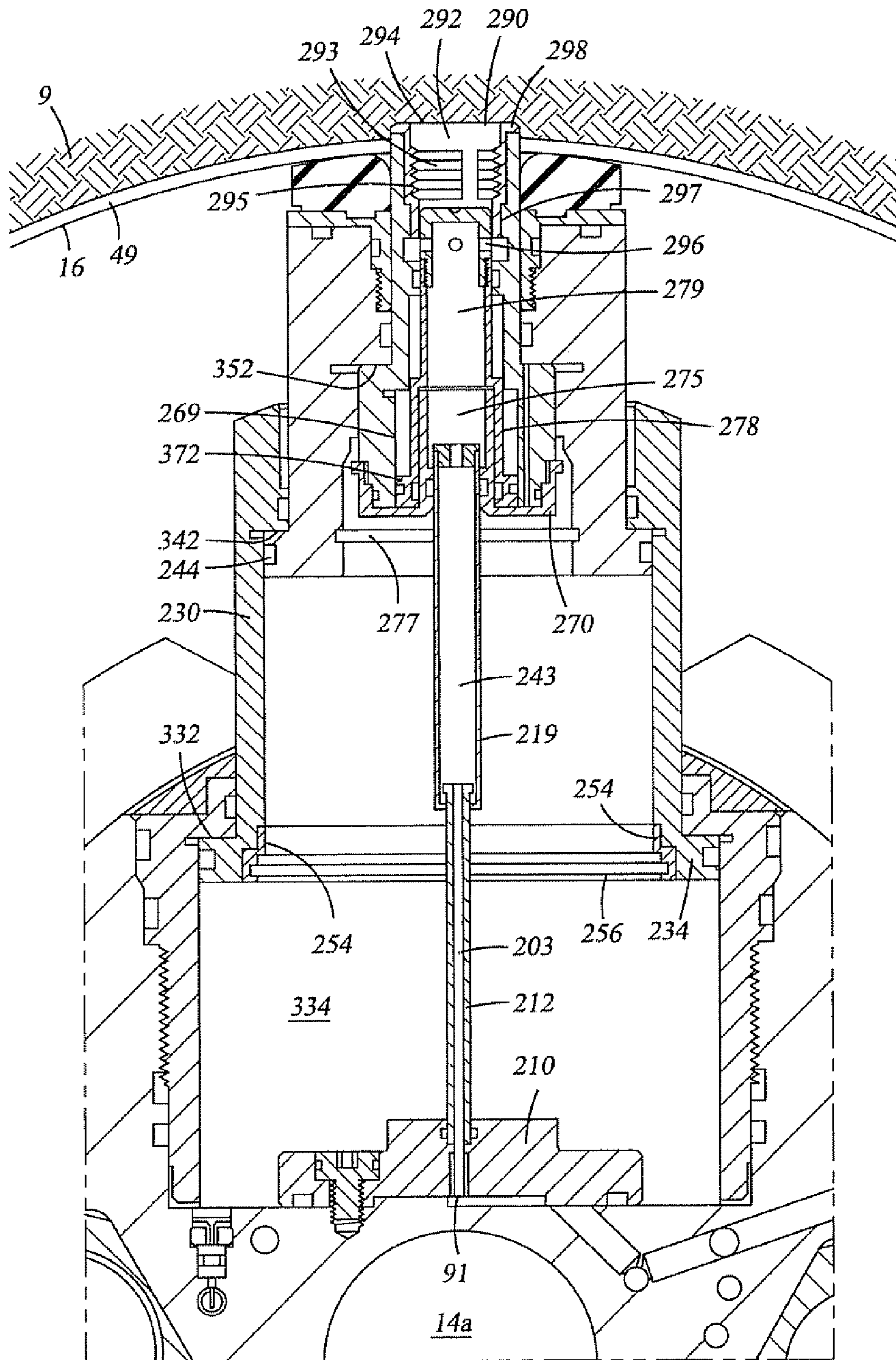


Fig. 7F

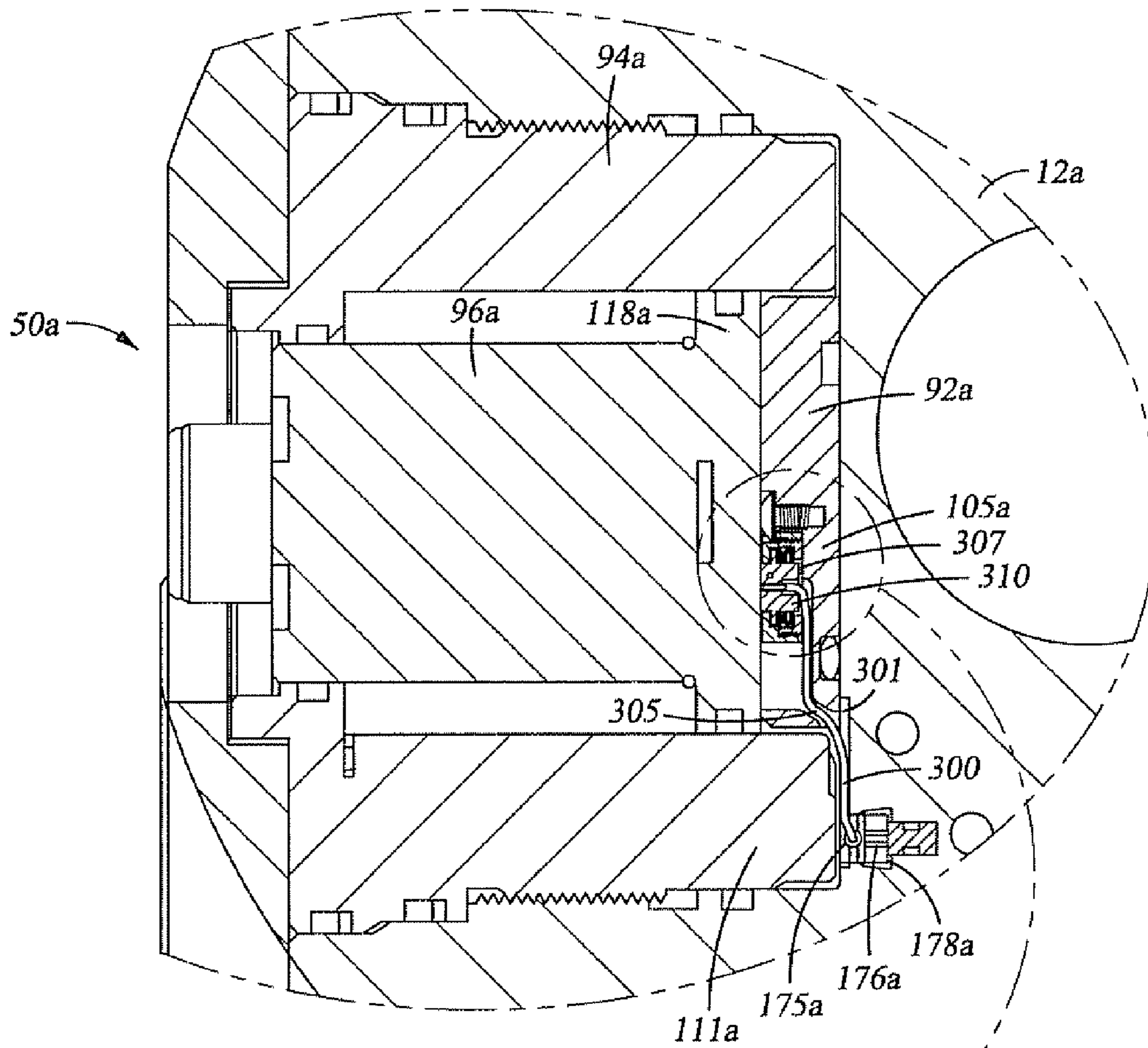


Fig. 8A

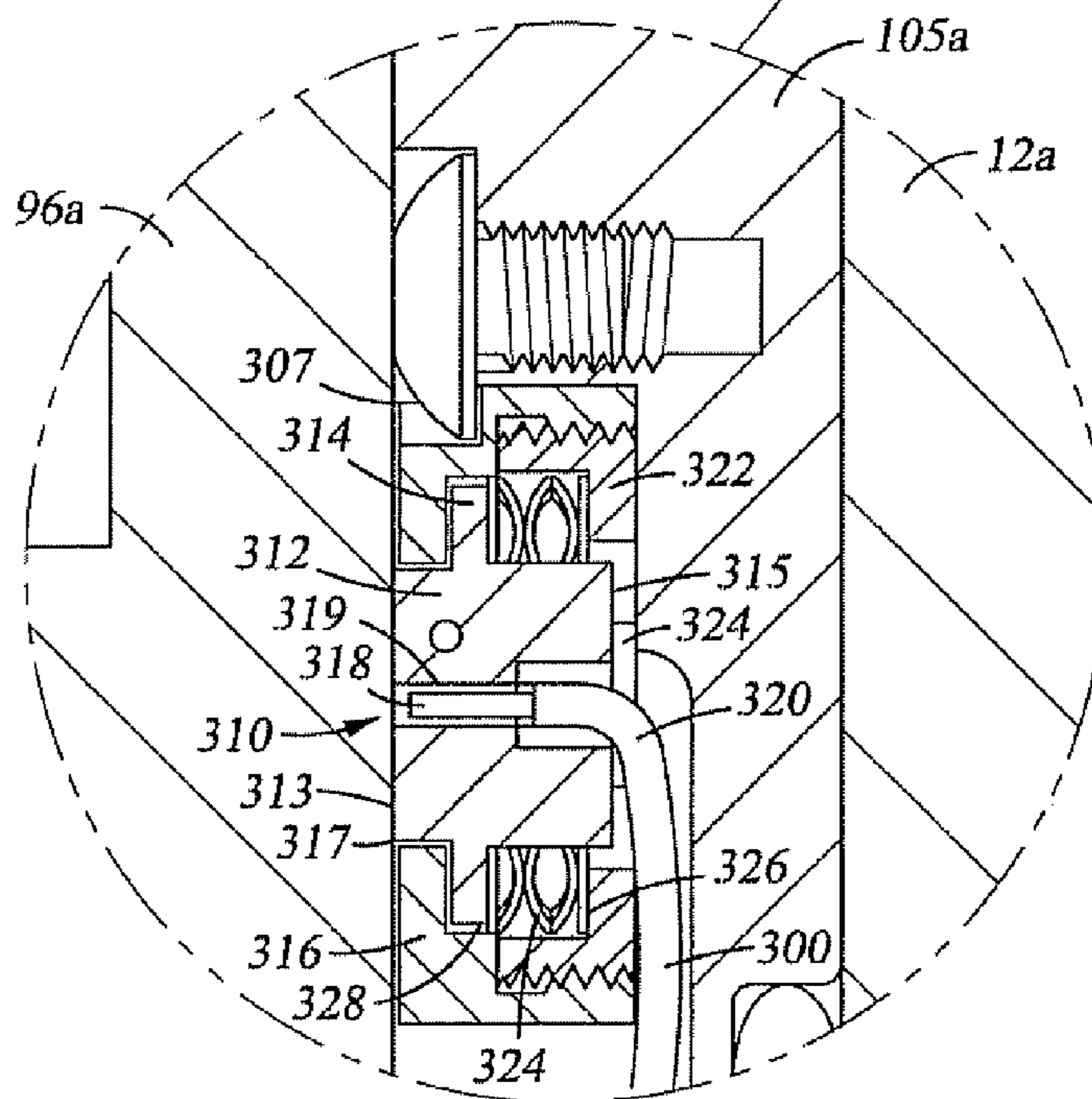


Fig. 8B

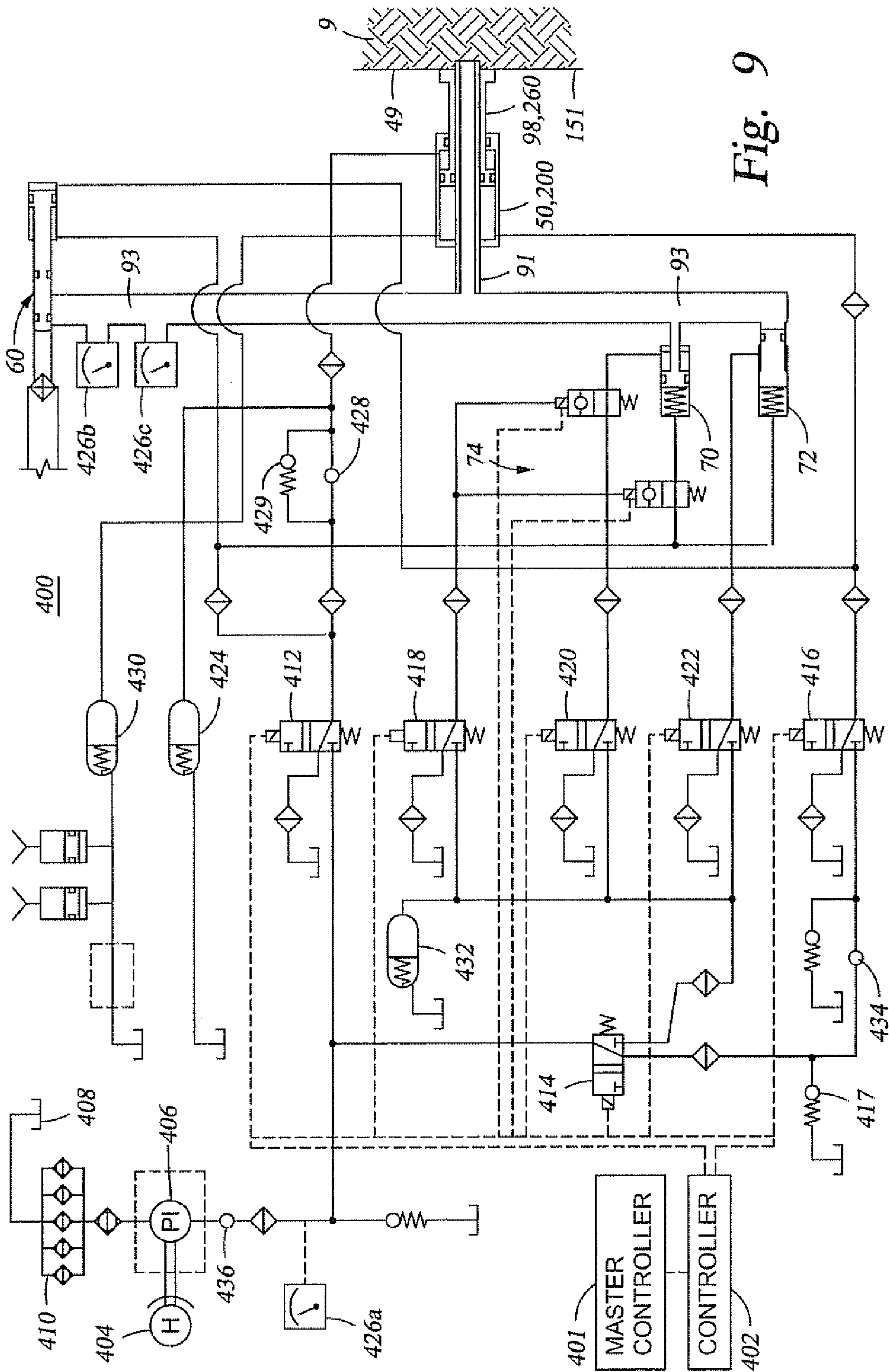


Fig. 9

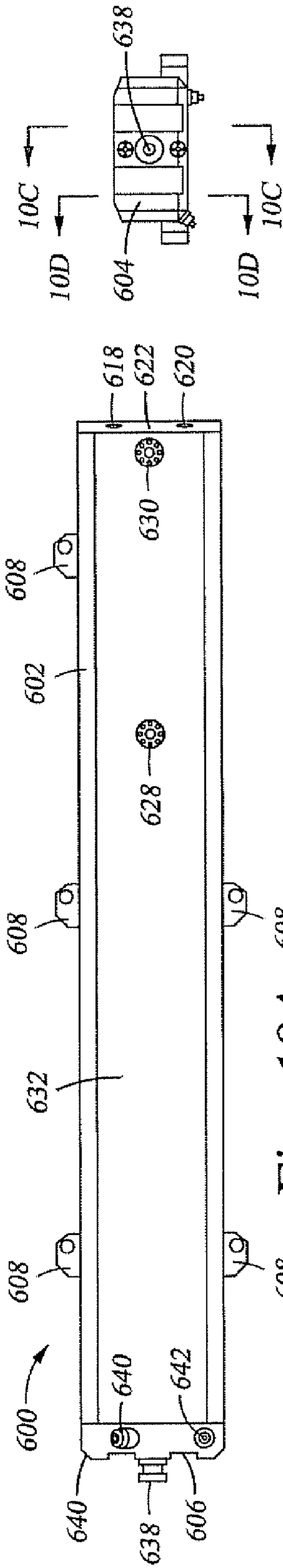


Fig. 10A

Fig. 10B

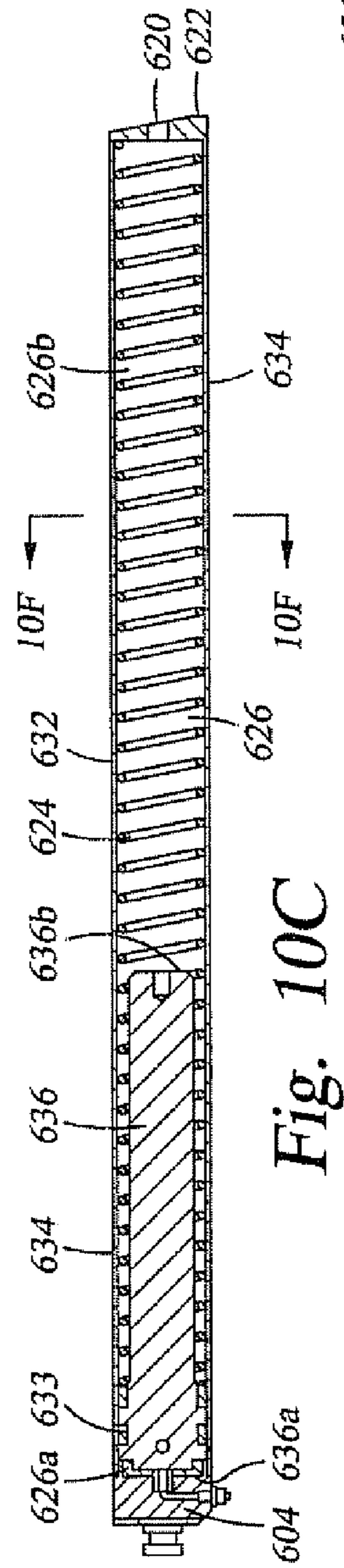


Fig. 10C

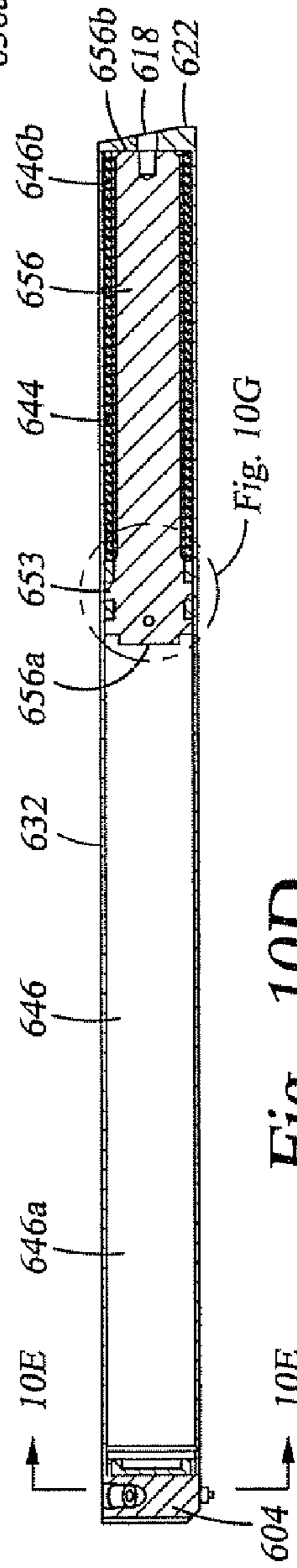


Fig. 10D

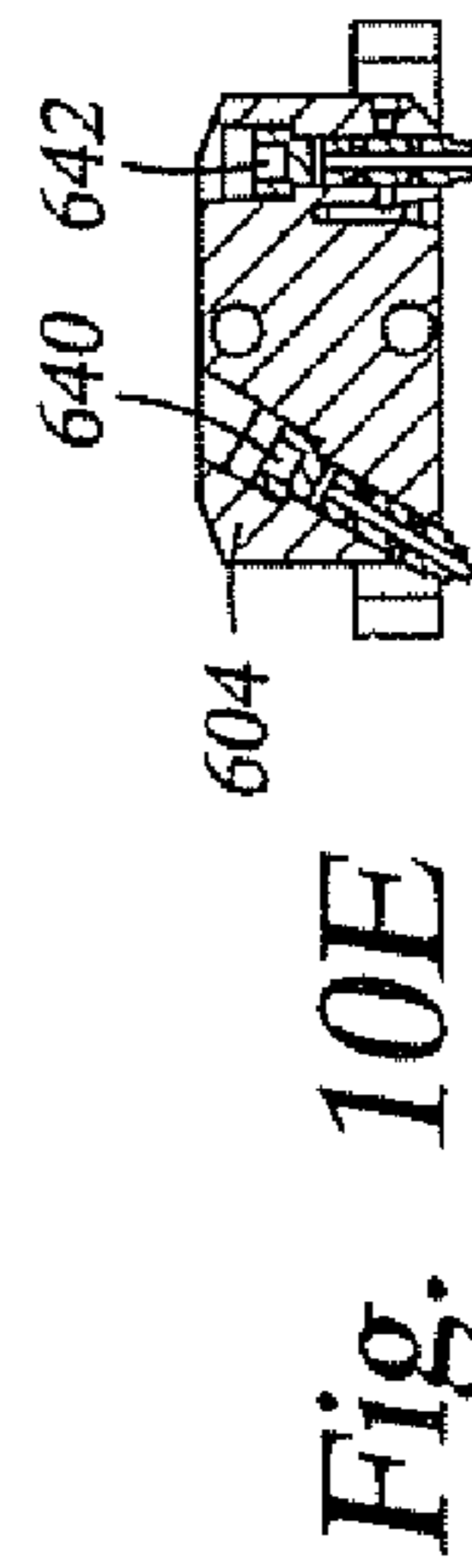


Fig. 10E

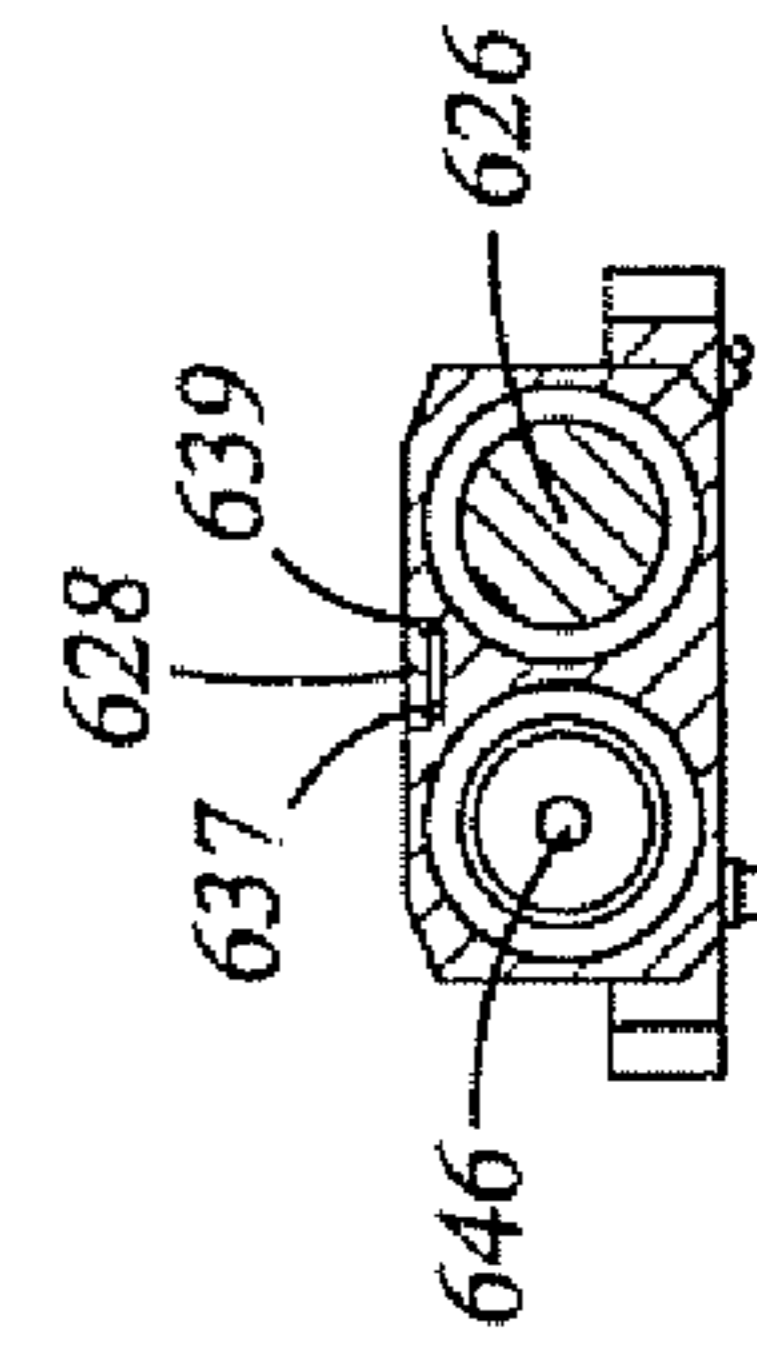


Fig. 10F

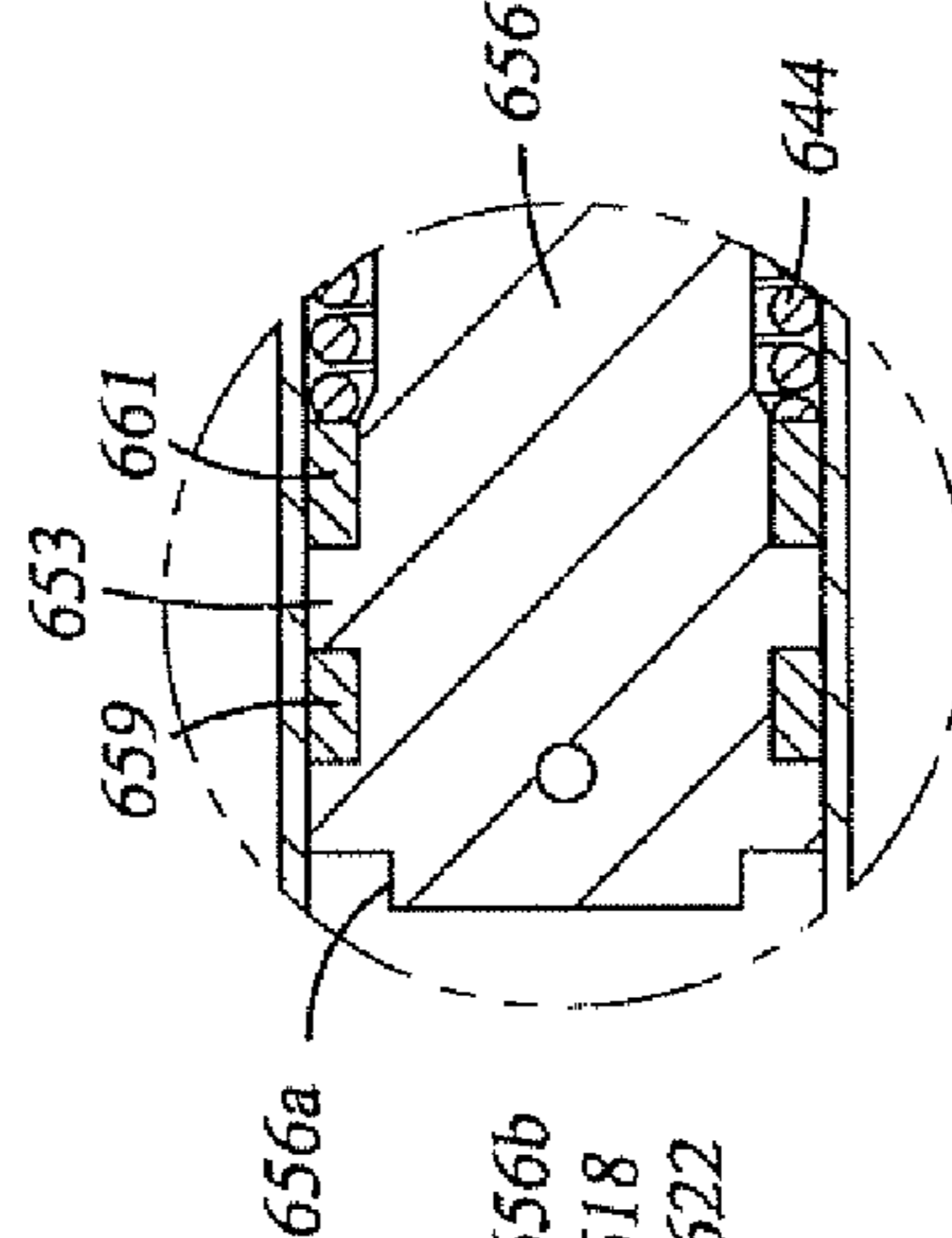


Fig. 10G

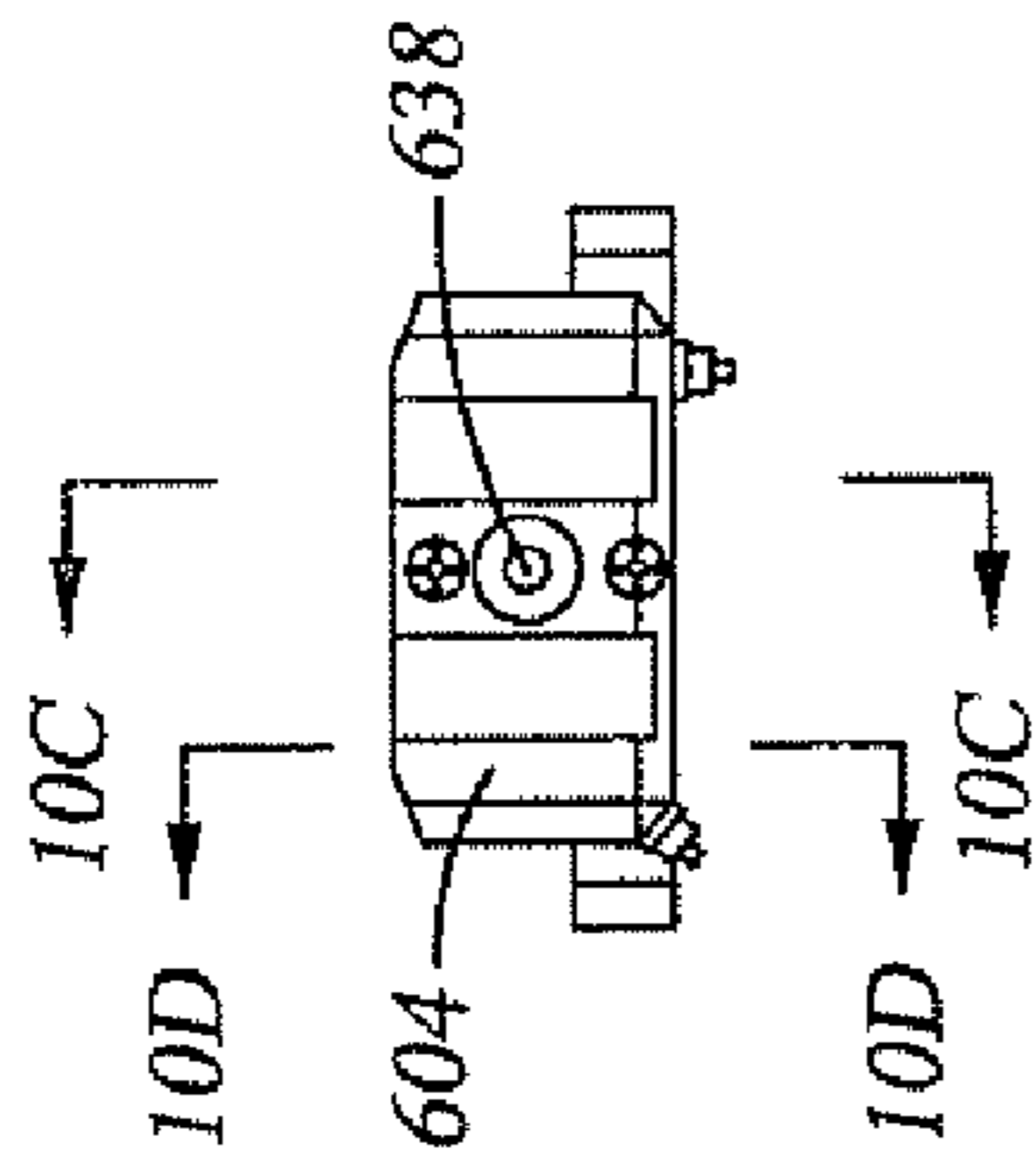


Fig. 10H

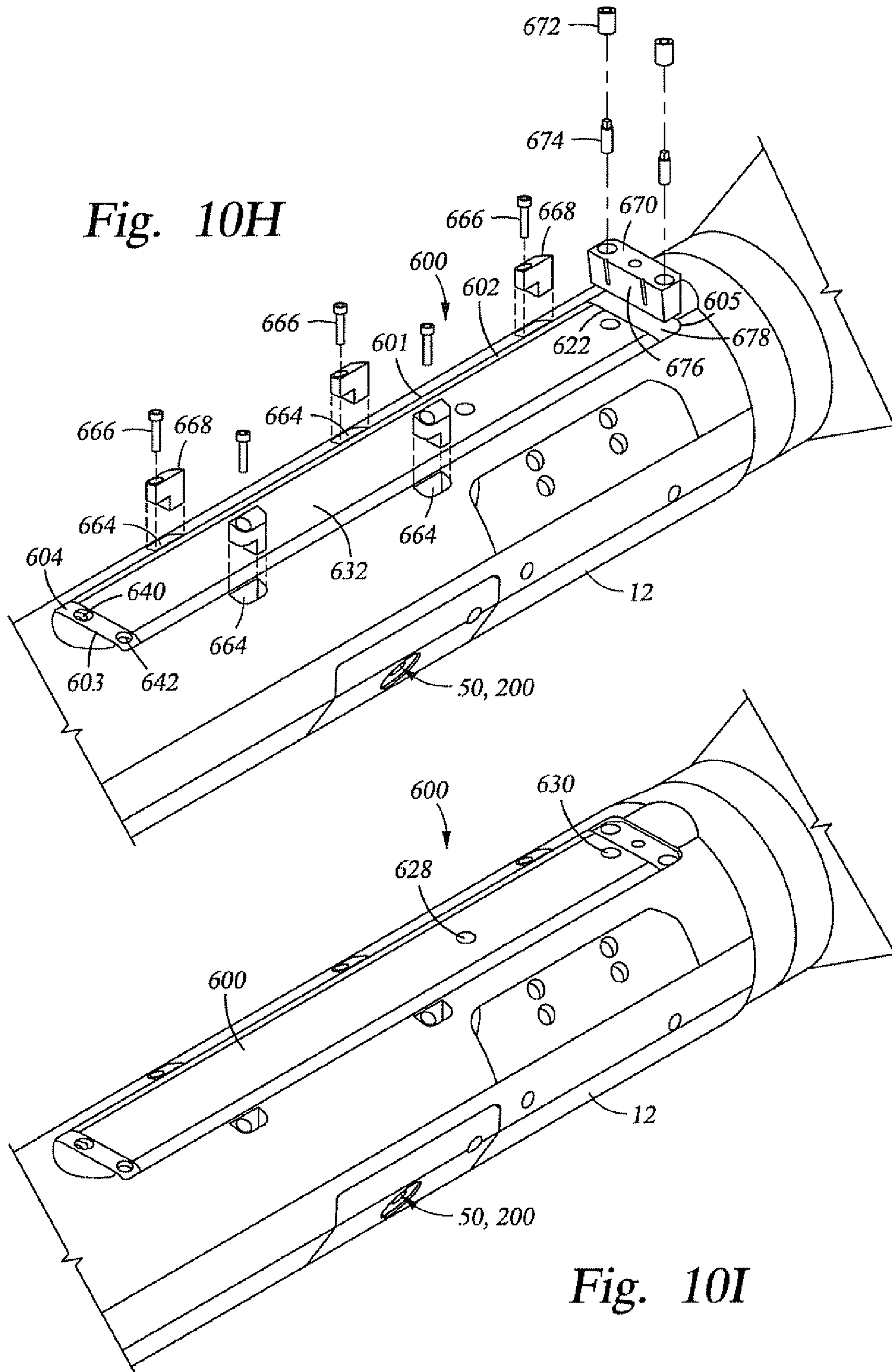


Fig. 10H

Fig. 10I

Fig. 11

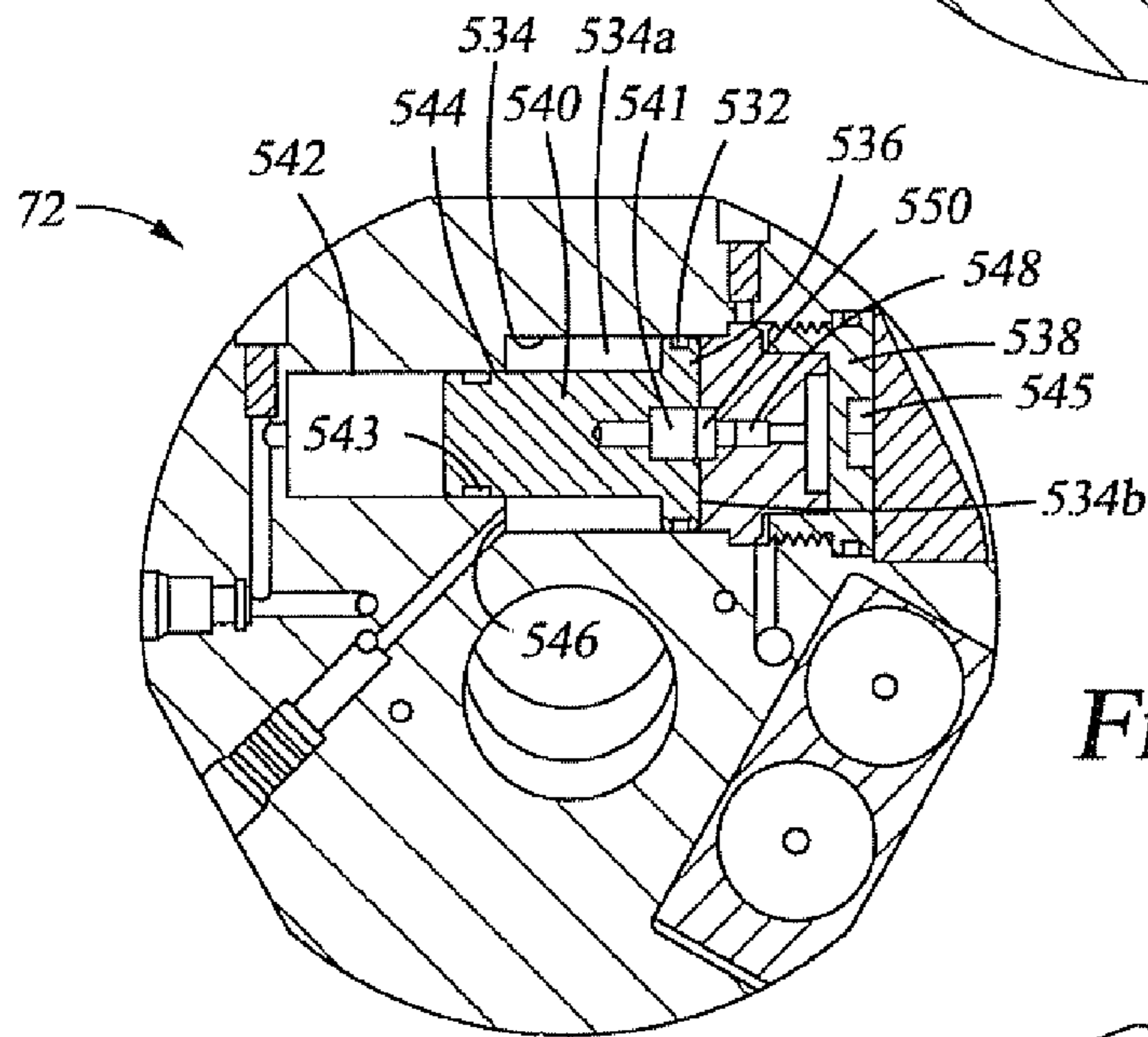
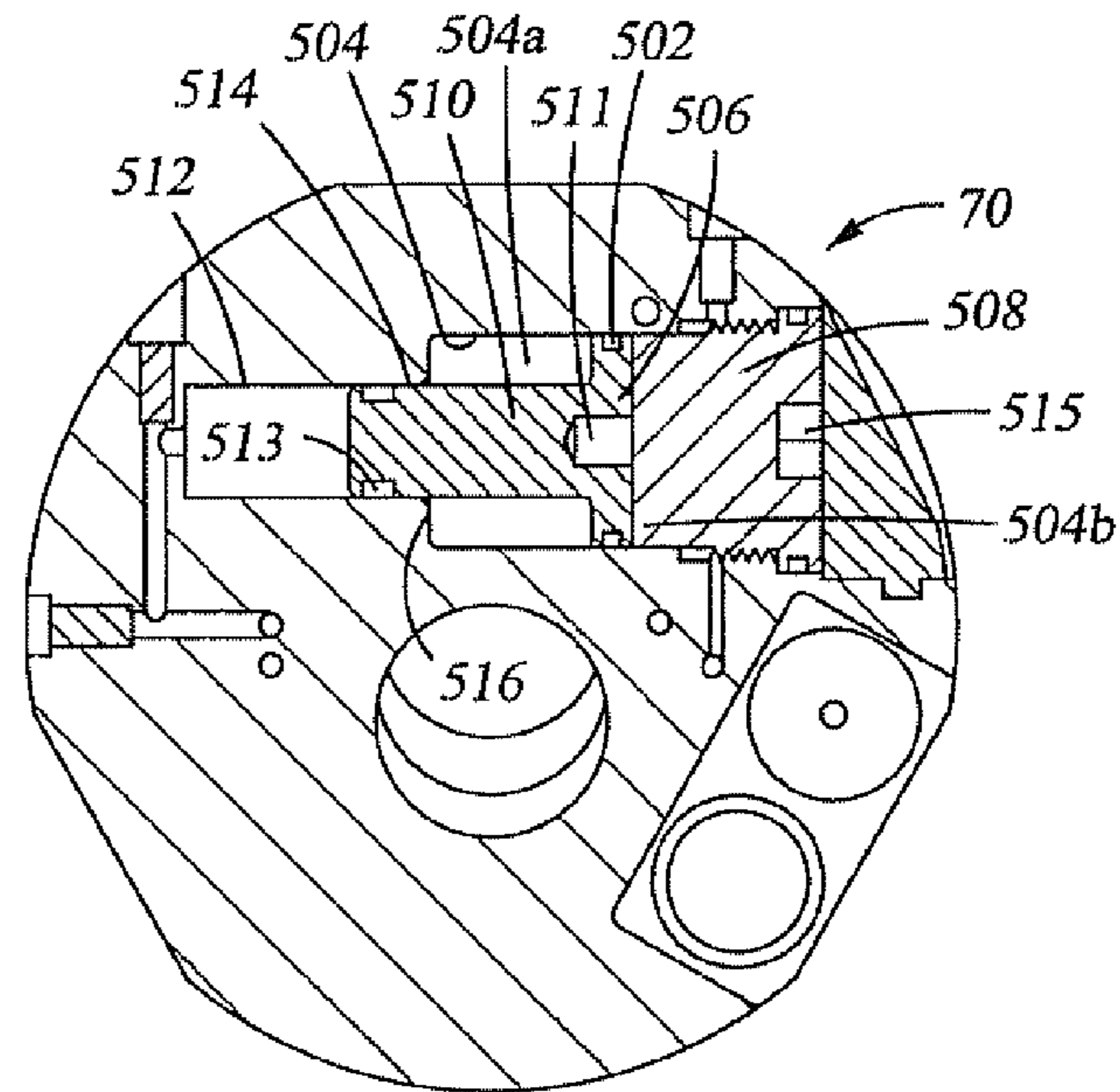


Fig. 12

Fig. 13

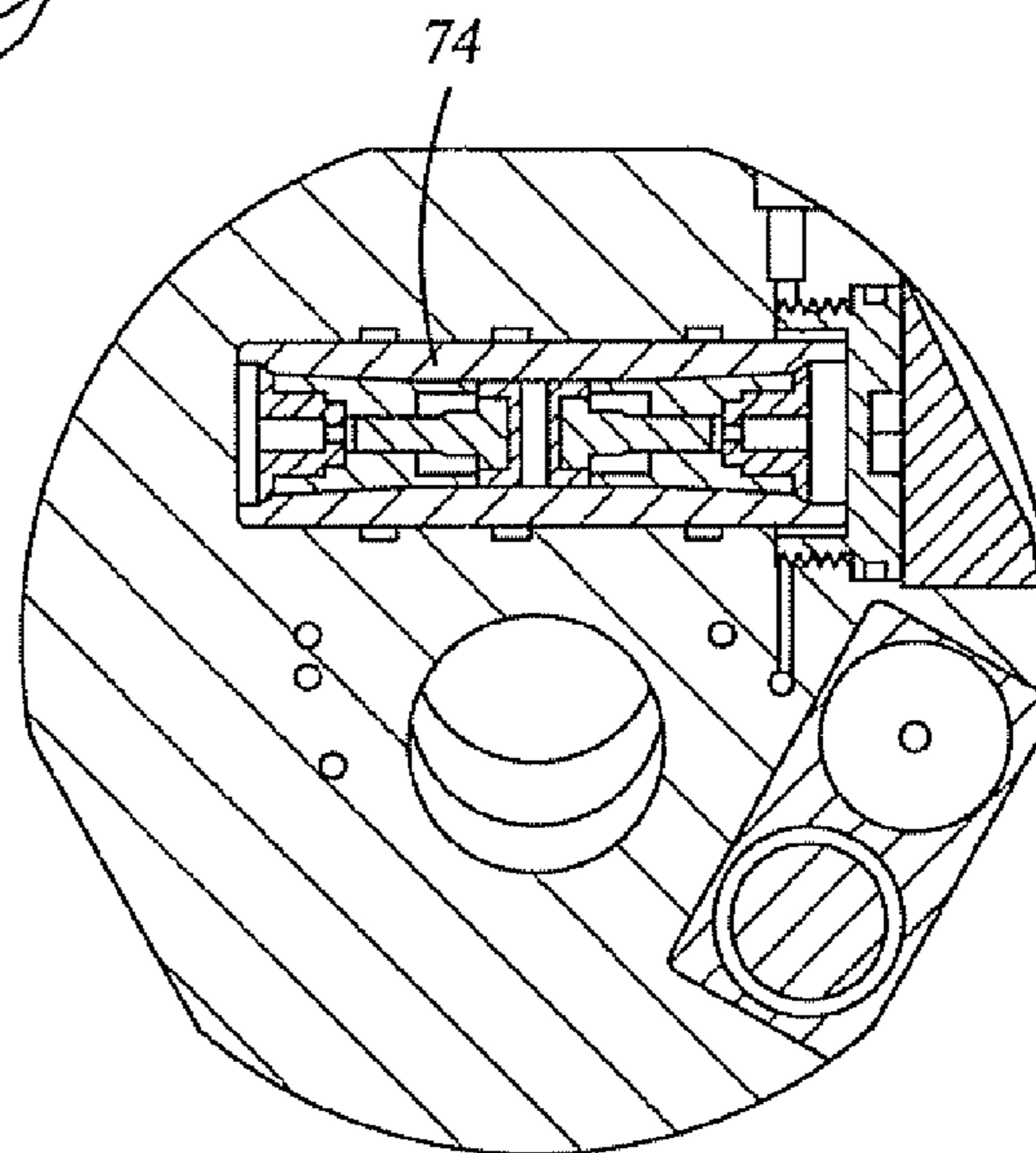
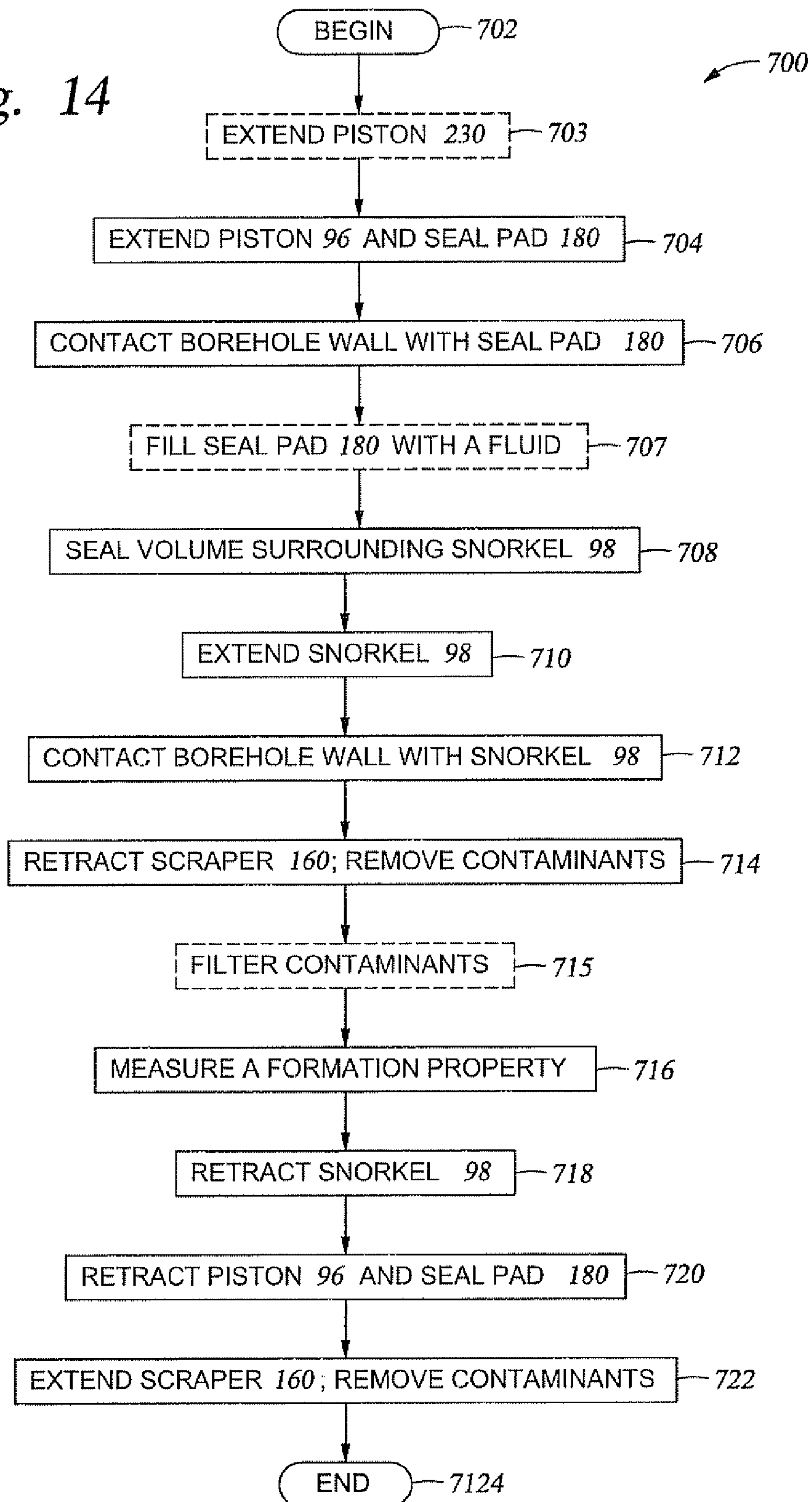


Fig. 14



1**FORMATION TESTER TOOL ASSEMBLY
AND METHODS OF USE****CROSS-REFERENCE TO RELATED
APPLICATIONS**

The present application claims the benefit of U.S. Provisional Application Ser. No. 60/573,293, filed May 21, 2004, entitled Formation Tester Tool Assembly and Methods of Use, which is hereby incorporated herein by reference.

**STATEMENT REGARDING FEDERALLY
SPONSORED RESEARCH OR DEVELOPMENT**

Not applicable.

BACKGROUND

During the drilling and completion of oil and gas wells, it may be necessary to engage in ancillary operations, such as monitoring the operability of equipment used during the drilling process or evaluating the production capabilities of formations intersected by the wellbore. For example, after a well or well interval has been drilled, zones of interest are often tested to determine various formation properties such as permeability, fluid type, fluid quality, formation temperature, formation pressure, bubblepoint and formation pressure gradient. These tests are performed in order to determine whether commercial exploitation of the intersected formations is viable and how to optimize production.

Wireline formation testers (WFT) and drill stem testing (DST) have been commonly used to perform these tests. The basic DST test tool consists of a packer or packers, valves or ports that may be opened and closed from the surface, and two or more pressure-recording devices. The tool is lowered on a work string to the zone to be tested. The packer or packers are set, and drilling fluid is evacuated to isolate the zone from the drilling fluid column. The valves or ports are then opened to allow flow from the formation to the tool for testing while the recorders chart static pressures. A sampling chamber traps clean formation fluids at the end of the test. WFTs generally employ the same testing techniques but use a wireline to lower the test tool into the well bore after the drill string has been retrieved from the well bore, although WFT technology is sometimes deployed on a pipe string. The wireline tool typically uses packers also, although the packers are placed closer together, compared to drill pipe conveyed testers, for more efficient formation testing. In some cases, packers are not used. In those instances, the testing tool is brought into contact with the intersected formation and testing is done without zonal isolation the axial span of the circumference of the borehole wall.

WFTs may also include a probe assembly for engaging the borehole wall and acquiring formation fluid samples. The probe assembly may include an isolation pad to engage the borehole wall. The isolation pad seals against the formation and around a hollow probe, which places an internal cavity in fluid communication with the formation. This creates a fluid pathway that allows formation fluid to flow between the formation and the formation tester while isolated from the borehole fluid.

In order to acquire a useful sample, the probe must stay isolated from the relative high pressure of the borehole fluid. Therefore, the integrity of the seal that is formed by the isolation pad is critical to the performance of the tool. If the borehole fluid is allowed to leak into the collected formation fluids, a non-representative sample will be obtained and the test will have to be repeated.

2

With the use of WFTs and DSTs, the drill string with the drill bit must be retracted from the borehole. Then, a separate work string containing the testing equipment, or, with WFTs, the wireline tool string, must be lowered into the well to conduct secondary operations. Interrupting the drilling process to perform formation testing can add significant amounts of time to a drilling program.

DSTs and WFTs may also cause tool sticking or formation damage. There may also be difficulties of running WFTs in highly deviated and extended reach wells. WFTs also do not have flowbores for the flow of drilling mud, nor are they designed to withstand drilling loads such as torque and weight on bit.

Further, the formation pressure measurement accuracy of drill stem tests and, especially, of wireline formation tests may be affected by filtrate invasion and mudcake buildup because significant amounts of time may have passed before a DST or WFT engages the formation. Mud filtrate invasion occurs when the drilling mud fluids displace formation fluids. Because the mud filtrate ingress into the formation begins at the borehole surface, it is most prevalent there and generally decreases further into the formation. When filtrate invasion occurs, it may become impossible to obtain a representative sample of formation fluids or, at a minimum, the duration of the sampling period must be increased to first remove the drilling fluid and then obtain a representative sample of formation fluids. The mudcake is made up of the solid particles that are deposited on the side of the well as the filtrate invades the near well bore during drilling. The prevalence of the mudcake at the borehole surface creates a "skin." Thus there may be a "skin effect" because formation testers can only withdraw fluids from relatively short distances into the formation, thereby distorting the representative sample of formation fluids due to the filtrate. The mudcake also acts as a region of reduced permeability adjacent to the borehole. Thus, once the mudcake forms, the accuracy of reservoir pressure measurements decreases, affecting the calculations for permeability and producibility of the formation.

Another testing apparatus is the measurement while drilling (MWD) or logging while drilling (LWD) tester. Typical LWD/MWD formation testing equipment is suitable for integration with a drill string during drilling operations. Various devices or systems are provided for isolating a formation from the remainder of the wellbore, drawing fluid from the formation, and measuring physical properties of the fluid and the formation. With LWD/MWD testers, the testing equipment is subject to harsh conditions in the wellbore during the drilling process that can damage and degrade the formation testing equipment before and during the testing process. These harsh conditions include vibration and torque from the drill bit, exposure to drilling mud, drilled cuttings, and formation fluids, hydraulic forces of the circulating drilling mud, and scraping of the formation testing equipment against the sides of the wellbore. Sensitive electronics and sensors must be robust enough to withstand the pressures and temperatures, and especially the extreme vibration and shock conditions of the drilling environment, yet maintain accuracy, repeatability, and reliability.

BRIEF DESCRIPTION OF THE DRAWINGS

For a more detailed description of preferred embodiments of the present invention, reference will now be made to the accompanying drawings, wherein:

FIG. 1 is a schematic elevation view, partly in cross-section, of an embodiment of a formation tester apparatus disposed in a subterranean well;

FIGS. 2A-2C are elevation views, in cross-section, of portions of the bottomhole assembly and formation tester assembly shown in FIG. 1;

FIGS. 3A-3B are enlarged elevation views, in cross-section, of the formation tester tool portion of the formation tester assembly shown in FIGS. 2B-2C;

FIG. 4 is an elevation view of the formation probe assembly and equalizer valve collar shown in FIG. 3B;

FIG. 5 is an enlarged cross-section view along line 5-5 of FIG. 4;

FIG. 6A is an enlarged view, in cross-section, of the formation probe assembly in a retracted position and equalizer valve shown in FIG. 5;

FIG. 6B is an enlarged view, in cross-section, of the formation probe assembly along line 6-6 of FIG. 4, the probe assembly being in an extended position;

FIGS. 7A-7F are cross-sectional views of another embodiment of the formation probe assembly taken along the same line as seen in FIG. 6B, the probe assembly being shown in a different position in each of FIGS. 7A-7F;

FIG. 8A is a schematic elevation view, in cross-section, of the probe retract switch portion of the formation probe assembly;

FIG. 8B is an enlarged view of the contact portion of the retract switch shown in FIG. 8A;

FIG. 9 is a schematic view of a hydraulic circuit employed in actuating the formation tester apparatus;

FIG. 10A is a top elevation view of a hydraulic reservoir accumulator assembly employed in the formation tester assembly;

FIG. 10B is an end view of the reservoir accumulator assembly of FIG. 10A;

FIG. 10C is a cross-section view taken along line C-C of FIG. 10B;

FIG. 10D is a cross-section view taken along line D-D of FIG. 10B;

FIG. 10E is a cross-section view taken along line E-E of FIG. 10D;

FIG. 10F is a cross-section view taken along line F-F of FIG. 10C;

FIG. 10G is an enlarged view of the detail of FIG. 10D;

FIGS. 10H-10I are perspective views of the reservoir accumulator assembly and probe collar; and

FIGS. 11-13 are elevation views, in cross-section, of the draw down piston and shutoff valve assemblies disposed in the probe collar of the formation tester assembly; and

FIG. 14 is a flow diagram of a formation test sequence.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Certain terms are used throughout the following description and claims to refer to particular system components. This document does not intend to distinguish between components that differ in name but not function.

In the following discussion and in the claims, the terms "including" and "comprising" are used in an open-ended fashion, and thus should be interpreted to mean "including, but not limited to . . .". Also, the terms "couple," "couples", and "coupled" used to describe any electrical connections are each intended to mean and refer to either an indirect or a direct electrical connection. Thus, for example, if a first device "couples" or is "coupled" to a second device, that interconnection may be through an electrical conductor

directly interconnecting the two devices, or through an indirect electrical connection via other devices, conductors and connections. Further, reference to "up" or "down" are made for purposes of ease of description with "up" meaning towards the surface of the borehole and "down" meaning towards the bottom or distal end of the borehole. In addition, in the discussion and claims that follow, it may be sometimes stated that certain components or elements are in fluid communication. By this it is meant that the components are constructed and interrelated such that a fluid could be communicated between them, as via a passageway, tube, or conduit. Also, the designation "MWD" or "LWD" are used to mean all generic measurement while drilling or logging while drilling apparatus and systems.

To understand the mechanics of formation testing, it is important to first understand how hydrocarbons are stored in subterranean formations. Hydrocarbons are not typically located in large underground pools, but are instead found within very small holes, or pore spaces, within certain types of rock. Therefore, it is critical to know certain properties of both the formation and the fluid contained therein. At various times during the following discussion, certain formation and formation fluid properties will be referred to in a general sense. Such formation properties include, but are not limited to: pressure, permeability, viscosity, mobility, spherical mobility, porosity, saturation, coupled compressibility porosity, skin damage, and anisotropy. Such formation fluid properties include, but are not limited to: viscosity, compressibility, flowline fluid compressibility, density, resistivity, composition and bubble point.

Permeability is the ability of a rock formation to allow hydrocarbons to move between its pores, and consequently into a wellbore. Fluid viscosity is a measure of the ability of the hydrocarbons to flow, and the permeability divided by the viscosity is termed "mobility." Porosity is the ratio of void space to the bulk volume of rock formation containing that void space. Saturation is the fraction or percentage of the pore volume occupied by a specific fluid (e.g., oil, gas, water, etc.). Skin damage is an indication of how the mud filtrate or mud cake has changed the permeability near the wellbore. Anisotropy is the ratio of the vertical and horizontal permeabilities of the formation.

Resistivity of a fluid is the property of the fluid which resists the flow of electrical current. Bubble point occurs when a fluid's pressure is brought down at such a rapid rate, and to a low enough pressure, that the fluid, or portions thereof, changes phase to a gas. The dissolved gases in the fluid are brought out of the fluid so gas is present in the fluid in an undissolved state. Typically, this kind of phase change in the formation hydrocarbons being tested and measured is undesirable, unless the bubblepoint test is being administered to determine what the bubblepoint pressure is.

In the drawings and description that follows, like parts are marked throughout the specification and drawings with the same reference numerals, respectively. The drawing figures are not necessarily to scale. Certain features of the invention may be shown exaggerated in scale or in somewhat schematic form and some details of conventional elements may not be shown in the interest of clarity and conciseness. The present invention is susceptible to embodiments of different forms. Specific embodiments are described in detail and are shown in the drawings, with the understanding that the present disclosure is to be considered an exemplification of the principles of the invention, and is not intended to limit the invention to that illustrated and described herein. It is to be fully recognized that the different teachings of the embodiments discussed below may be employed separately

5

or in any suitable combination to produce desired results. The various characteristics mentioned above, as well as other features and characteristics described in more detail below, will be readily apparent to those skilled in the art upon reading the following detailed description of the embodiments, and by referring to the accompanying drawings.

Referring to FIG. 1, a formation tester tool 10 is shown as a part of bottom hole assembly 6 which includes an MWD sub 13 and a drill bit 7 at its lower most end. Bottom hole assembly 6 is lowered from a drilling platform 2, such as a ship or other conventional platform, via drill string 5. Drill string 5 is disposed through riser 3 and well head 4. Conventional drilling equipment (not shown) is supported within derrick 1 and rotates drill string 5 and drill bit 7, causing bit 7 to form a borehole 8 through the formation material 9. The borehole 8 penetrates subterranean zones or reservoirs, such as reservoir 11, that are believed to contain hydrocarbons in a commercially viable quantity. It should be understood that formation tester 10 may be employed in other bottom hole assemblies and with other drilling apparatus in land-based drilling, as well as offshore drilling as shown in FIG. 1. In all instances, in addition to formation tester 10, the bottom hole assembly 6 contains various conventional apparatus and systems, such as a down hole drill motor, rotary steerable tool, mud pulse telemetry system, measurement-while-drilling sensors and systems, and others well known in the art.

It should also be understood that, even though formation tester 10 is shown as part of drill string 5, the embodiments of the invention described below may be conveyed down borehole 8 via wireline technology, as is partially described above, or via a rotary steerable drill string that is well known to one skilled in the art. Further context and examples for methods of use of the embodiments described herein may be obtained from U.S. Patent Application entitled "Downhole Probe Assembly," having Ser. No. 11/133,643; U.S. Patent Application entitled "Methods for Using a Formation Tester," having Ser. No. 11/132,475; and U.S. Patent Application entitled "Methods for Measuring a Formation Supercharge Pressure," having U.S. patent application Ser. No. 11/069,649; each hereby incorporated herein by reference for all purposes.

Referring now to FIGS. 2A-C, portions of the formation tester tool 10 are shown. FIG. 2A illustrates the electronics module 20, which may include battery packs, various circuit boards, capacitors banks and other electrical components. FIG. 2B shows fillport assembly 22 having fillports 24, 26 for adding or removing hydraulic or other fluids to the tool 10. Below fillport assembly 22 is hydraulic insert assembly 30. Below assembly 30 is the hydraulic connectors ring assembly 32, which acts as a hydraulic line manifold. FIG. 2C illustrates the portion of tool 10 including equalizer valve 60, formation probe assembly 50 (or probe assembly 200), draw down shutoff valve assembly 74, draw down piston assemblies 70, 72 and stabilizer 36. Also included is pressure instrument assembly 38, including the pressure transducers used by formation probe assemblies 50, 200.

Referring to FIGS. 3A-B now, the enlarged portions of tool 10 shown in FIGS. 2B-C are shown. Hydraulic insert assembly 30, probe retract accumulator 424, equalizer valve 60, formation probe assembly 50, draw down shutoff valve 74 and draw down piston assemblies 70, 72 can be seen in greater detail. Equalizer valve 60 may be any of a variety of equalizer valves known to one skilled in the art.

Referring now to FIG. 4, formation probe assembly 50 is disposed within probe drill collar 12, and covered by probe

6

cover plate 51. Also disposed within probe collar 12 is an equalizer valve 60 having a valve cover plate 61. Adjacent formation probe assembly 50 and equalizer valve 60 is a flat 136 in the surface 17 of probe collar 12. Probe drill collar 12 includes a draw down cover 76 for protecting other devices associated with the formation probe assembly 50 mounted in the collar 12, such as draw down pistons (not shown).

As best shown in FIG. 5, it can be seen how formation probe assembly 50 and equalizer valve 60 are positioned in probe collar 12. Formation probe assembly 50 and equalizer valve 60 are mounted in probe collar 12 just above the flowbore 14. Flowbore 14 may be deviated from the center longitudinal axis 12a of probe collar 12, or from other portions 14b, 14c of flowbore 14, to accommodate at least formation probe assembly 50. For example, in FIG. 5, flowbore portion 14a is offset radially from the longitudinal axis 12a, and also from the flowbore portion 14b via transition flowbore portion 14c. Also shown are draw down piston assemblies 70, 72 and draw down shutoff valve 74.

The details of a first embodiment of formation probe assembly 50 are best shown in FIG. 6A-6B. In FIG. 6A, formation probe assembly 50 is retained in probe collar 12 by threaded engagement with collar 12 and also by cover plate 51. Formation probe assembly 50 generally includes stem 92, a generally cylindrical threaded adapter sleeve 94, piston 96 adapted to reciprocate within adapter sleeve 94, and a snorkel assembly 98 adapted for reciprocal movement within piston 96. Probe collar 12 includes an aperture 90 for receiving formation probe assembly 50. Cover plate 51 fits over the top of formation probe assembly 50 and retains and protects formation probe assembly 50 when the formation probe assembly 50 is within probe collar 12. Formation probe assembly 50 may extend and retract through aperture 52 in cover plate 51.

Stem 92 includes a circular base portion 105 with an outer flange 106 having stem holding screw 97 (shown in FIG. 6B) for retaining stem 92 in aperture 90. Extending from base 105 is a tubular extension 107 having central passageway 108. The end of extension 107 includes internal threads at 109. Central passageway 108 is in fluid connection with fluid passageway 91 (not shown, but seen schematically in FIG. 9) that connects to fluid passageway 93 (not shown, but seen schematically in FIG. 9) leading to other portions of tool 10, including equalizer valve 60.

Adapter sleeve 94 includes inner end 111 that engages flange 106 of stem 92. Adapter sleeve 94 is secured within aperture 90 by threaded engagement with collar 12 at segment 110. The outer end 112 of adapter sleeve 94 may extend to be substantially flushed with recess 55 formed in collar 12 for receiving cover plate 51. Outer end 112 also includes flange 158 for engaging recess 162 of cover plate 51. Adapter sleeve 94 includes cylindrical inner surface 113 having reduced diameter portions 114, 115. A seal 116 is disposed in surface 114.

Piston 96 is slidingly retained within adapter sleeve 94 and generally includes cylindrical outer surface 141 having an increased diameter base portion 118. A seal 143 is disposed in increased diameter portion 118. Just below base portion 118, piston 96 may rest on flange 106 of stem base portion 105 while formation probe assembly 50 is in the fully retracted position as shown in FIG. 6A. Piston 96 may also include cylindrical inner surface 145 having reduced diameter portion 147. Piston 96 may further include central bore 121 having a bore surface 120 and extending through upper extending portion 119.

Referring to FIG. 6B, at the top of extending portion 119 of piston 96 is a seal pad 180. Seal pad 180 may be

donut-shaped with a curved outer sealing surface **183** and central aperture **186**. However, seal pad **180** may include numerous other geometries as is known in the art, or, for example, as is seen in U.S. patent application Ser. No. 10/440,835 entitled "MWD Formation Tester." Base surface **185** of seal pad **180** may be coupled to a skirt **182**. Seal pad **180** may be bonded to skirt **182**, or otherwise coupled to skirt **182**, such as by molding seal pad **180** onto skirt **182** such that the seal pad material fills grooves or holes in skirt **182**, as can be seen in U.S. patent application Ser. No. 10/440,835. Skirt **182** is detachably coupled to extending portion **119** by way of threaded engagement with surface **120** of central bore **121** (see FIG. 6A), or other means of engagement, such as a pressure fit with central bore surface **120**. Because the seal pad/skirt combination may be detachable from extending portion **119**, it is easily replaced in the field. Alternatively, seal pad **180** may be coupled directly to extending portion **119** without using a skirt.

Seal pad **180** is preferably made of an elastomeric material. Seal pad **180** seals and prevents drilling fluid or other contaminants from entering the formation probe assembly **50** during formation testing. More specifically, seal pad **180** may seal against the filter cake that may form on a borehole wall. Typically, the pressure of the formation fluid is less than the pressure of the drilling fluids that are injected into the borehole. A layer of residue from the drilling fluid forms a filter cake on the borehole wall and separates the two pressure areas. Seal pad **180**, when extended, may conform its shape to the borehole wall and/or mud cake and forms a seal through which formation fluids can be collected and/or formation properties measured.

In an alternative embodiment of the seal pad **180**, the seal pad **180** may have an internal cavity such that it can retain a volume of fluid. A fluid may be pumped into the seal pad cavity at variable rates such that the pressure in the seal pad cavity may be increased and decreased. Fluids used to fill the seal pad may include hydraulic fluid, saline solution or silicone gel. By way of example, the seal pad may be emptied or unpressured as the probe extends to engage the borehole wall. Depending on the contour of the borehole wall, the seal pad may be pressured by filling the seal pad with fluid, thereby conforming the seal pad surface to the contour of the borehole wall and providing a better seal.

In yet another embodiment of the seal pad, the seal pad may be filled, either before or after engagement with the borehole wall, with an electro-rheological fluid. An electro-rheological fluid may be an insulating oil containing a dispersion of fine solid particles, for example, 5 μm to 50 μm in diameter. Such an electro-rheological fluid is well known in the art. When subjected to an electric field, these fluids develop an increased shear stress and an increased static yield stress that make them more resistant to flow. This change of fluid properties is evident, for example, as an increase in viscosity, most notably the plastic viscosity, when the electric field is applied. The fluid in the seal pad may effectively become semi-solid. The semi-solid effect is reversed when the fluid is no longer subjected to the electric field. In the absence of the electric field, the electro-rheological fluid that may fill the seal pad becomes less viscous, causing the seal pad to conform to the contour of a borehole wall. Once the seal pad has conformed to the borehole wall, an electric field may be applied to the electro-rheological fluid inside the seal pad, causing an increase in fluid viscosity, a stiffening of the seal pad, and a better seal.

Still referring to FIG. 6B, snorkel assembly **98** includes a base portion **125**, a snorkel extension **126**, and a central passageway **127** extending through base **125** and extension

126. Base portion **125** may include a cylindrical outer surface **122** and inner surface **124**. Extension **126** may include a cylindrical outer surface **128** and inner surface **138**. Disposed inside the top of extension **126** is a screen **100**. Screen **100** is a generally tubular member having a central bore **132** extending between a fluid inlet end **131** and fluid outlet end **135**. Screen **100** further includes a flange **130** adjacent to fluid inlet end **131** and an internally slotted segment **133** having slots **134**. Between slotted segment **133** and outlet end **135**, screen **100** includes threaded segment **137** for threadedly engaging snorkel extension **126**.

Threaded to the bottom of base portion **125** of snorkel **98** is scraper tube keeper **152** having a circular base portion **154** with flange **153**, a tubular extension **156** having a central passageway **155** and a central aperture **157** for receiving stem extension **107**. Just below scraper tube keeper **152** is retainer ring **159**, which provides seated engagement with snorkel **98** such that the movement of snorkel **98** is limited in the retract direction. Scraper tube keeper **152** supports scraper tube **150** when scraper tube **150** is in the retracted position shown in FIG. 6B. Scraper tube **150** having central passageway **151** extends up from scraper tube keeper **152** and through passageway **127** of snorkel **98**. Coupled at the top of scraper tube **150** is scraper or wiper **160**. Scraper **160** is threadedly engaged with scraper tube **150** at threaded segment **161**. Scraper **160** is a generally cylindrical member including scraper plug portion **163**, central bore **164** and apertures **166** that are in fluid communication with central bore **164**. Scraper **160** is disposed within central bore **132** of screen **100** and may be actuated back and forth (or reciprocal) between screen inlet end **131** and outlet end **135**. When scraper tube **150** and scraper **160** are in their retracted positions, as shown in FIG. 6B, apertures **166** are in fluid communication with fluid outlet end **135** of screen **100**, thereby allowing fluid to pass from screen **100**, through scraper bore **164**, and into central passageway **155** of scraper tube **150**. Scraper or wiper **160** is thus configured to be a moveable or floating scraper.

In an alternative embodiment of the scraper **160** within the screen **100**, the actuation of scraper **160** may be a rotational movement around the longitudinal axis of scraper **160**. This rotational movement may be in place of the reciprocal movement, or in addition to the reciprocal movement.

As shown in FIG. 6B, a connector **176** is disposed in aperture **178** of probe collar **12**, just beneath inner end **111** of sleeve **94**. Contact lead **175** electrically connects connector **176**, via a wire, to a contact assembly (not shown) preferably disposed in flange **106** of stem base portion **105** so that the contact assembly can be in direct contact with base portion **118** of piston **96**. FIGS. 8A-8B show the details of connector **176** and contact assembly **310**, with the surrounding structures shown in a more general fashion such that the different parts of formation probe assembly **50a** generally correspond with similar parts of formation probe assembly **50** of FIGS. 6A-6B.

Referring first to FIG. 8A, connector **176a** is disposed in aperture **178a** in probe collar **12a**. Contact lead **175a** is coupled to wire **300**, which extends through recess **301** in collar **12a** to opening **305** in base portion **105a** of stem **92a**. From opening **305**, wire **300** extends through base portion **105a** to a cavity **307**, where contact assembly **310** is disposed.

Referring now to FIG. 8B, wire **300** leads into contact assembly **310**. Contact assembly **310** generally includes housing **316** having aperture **317**, a conductive contact body **312** having a flange **314** and a central bore **319**, a stripped

end 318 of wire 300 extending into and soldered to bore 319, a non-conductive spring support 322, and wave springs 324. The flange 314 of body 312 is disposed between the upper portion of housing 316 and the lower portion of spring support 322. Disposed between spring support 322 and flange 314 are wave springs 324, which are supported by lower plate 326 and upper plate 328. Springs 324 provide an upward force on flange 314 such that top surface 313 of body 312 extends out of aperture 317 such that top surface 313 protrudes out of cavity 307. As formation probe assembly 50a is retracting, piston 96a comes into contact with and presses downward on surface 313 of body 312, causing springs 324 to compress and bottom surface 315 to move downward into space 324. When piston 96a contacts surface 313 of body 312, an electric circuit is completed to ground (not shown) through piston 96a, providing a signal to the tool electronics (not shown) that formation probe assembly 50a has been fully retracted. After piston 96a makes contact with surface 313 of body 312, piston 96a continues to travel until making contact with base portion 105a of stem 92a. Heat shrink 320 is shrunk in place over wire 300 for mechanical protection.

Referring now to FIGS. 6A and 6B, formation probe assembly 50 is assembled such that piston base 118 is permitted to reciprocate along surface 113 of adapter sleeve 94, and piston outer surface 141 is permitted to reciprocate along surface 114. Similarly, snorkel base 125 is disposed within piston 96 and is adapted for reciprocal movement along surface 147 while flange 153 of scraper tube keeper 152 reciprocates along surface 145. Snorkel extension 126 is adapted for reciprocal movement along piston surface 120. Central passageway 127 of snorkel 98 is axially aligned with tubular extension 107 of stem 92, scraper tube keeper 152, scraper tube 150, scraper 160 and with screen 100. Formation probe assembly 50 is reciprocal between a fully retracted position, as shown in FIG. 6A, and a fully extended position, as shown in FIG. 6B. Also, scraper tube 150 is reciprocal between a fully retracted position, as shown in FIGS. 6A-6B, and a fully extended position, as is illustrated by a similar scraper tube 278 in FIGS. 7A-7E. When scraper tube 150 is fully retracted, fluid may be communicated between central passageway 108 of extension 107, passageway 155 of scraper tube keeper 152, passageway 151 of scraper 150, scraper bore 164, scraper apertures 166, screen 100, and the surrounding environment 15.

With reference to FIGS. 6A and 6B, the operation of formation probe assembly 50 will now be described. Formation probe assembly 50 is normally in the retracted position. Formation probe assembly 50 remains retracted when not in use, such as when the drill string is rotating while drilling if formation probe assembly 50 is used for an MWD application, or when the wireline testing tool is being lowered into borehole 8 if formation probe assembly 50 is used for a wireline testing application. FIG. 6A shows formation probe assembly 50 in the fully retracted position, except that scraper tube 150 is shown in the retracted position, and scraper tube 150 is typically extended when formation probe assembly 50 is in this position, as shown in FIGS. 7A-7E. FIGS. 7A-7F will be referred to in describing the operation of formation probe assembly 50 because the structures of formation probe assembly 50 previously described are similar to corresponding parts of probe assembly 200 seen in FIGS. 7A-7F.

Formation probe assembly 50 typically begins in the retracted position, as shown in FIG. 6A. Upon an appropriate command to formation probe assembly 50, a force is applied to base portion 118 of piston 96, preferably by using

hydraulic fluid. Piston 96 extends relative to the other portions of formation probe assembly 50 until retainer ring 159 engages flange 153 of scraper tube keeper 152. This position of piston 96 relative to snorkel assembly 98 can be seen in FIG. 7B. As hydraulic fluid continues to be pumped into hydraulic fluid reservoir 54, piston 96 and snorkel assembly 98 continue to move upward together. Base portion 118 slides along adapter sleeve surface 113 until base portion 118 comes into contact with shoulder 170. After such contact, formation probe assembly 50 will continue to pressurize reservoir 54 until reservoir 54 reaches a certain pressure P_1 . Alternatively, if seal pad 180 comes into contact with a borehole wall before base portion 118 comes into contact with shoulder 170, formation probe assembly 50 will continue to apply pressure to seal pad 180 by pressurizing reservoir 54 up to the pressure P_1 . The pressure P_1 applied to formation probe assembly 50, for example, may be 1,200 p.s.i.

The continued force from the hydraulic fluid in reservoir 54 causes snorkel assembly 98 to extend such that the outer end of snorkel extension 126, inlet end 131 of screen 100 and the top of scraper 160 extend beyond seal pad surface 183 through seal pad aperture 186. This snorkel extending force must overcome the retract force being applied on the retract side of snorkel base portion 125 facing piston shoulder 172. Previously, the retract force, provided by retract accumulator 424 and the retract valves, was greater than the extend force, thereby maintaining snorkel 98 in the retract position. However, the extend force continues to increase until it overcomes the retract force at, for example, 900 p.s.i. Snorkel assembly 98 stops extending outward when snorkel base portion 125 comes into contact with shoulder 172 of piston 96. Scraper tube 150 and scraper 160 are still in the extended position, as is best shown with the snorkel assembly and piston configuration of FIG. 7E.

Alternatively, if snorkel assembly 98 comes into contact with a borehole wall before snorkel base portion 125 comes into contact with shoulder 172 of piston 96, continued force from the hydraulic fluid pressure in reservoir 54 is applied up to the previously mentioned maximum pressure. The maximum pressure applied to snorkel assembly 98, for example, may be 1,200 p.s.i. Preferably, the snorkel and seal pad will contact the borehole wall before either piston 96 or snorkel 98 shoulders at full extension. Then, the force applied on the seal pad is reacted by stabilizer 36, or other similar device disposed on or near probe collar 12.

If, for example, seal pad 180 had made contact with the borehole wall 16 before being fully extended and pressurized, then seal pad 180 should seal against the mudcake on borehole wall 16 through a combination of pressure and seal pad extrusion. The seal separates snorkel assembly 98 from the mudcake, drilling fluids and other contaminants outside of seal pad 180. As the snorkel assembly extends, snorkel extension 126, screen inlet end 131 and the top of scraper 160 pierce the mudcake that has been sealed off, and preferably go through the entire mudcake layer and into formation 9.

With screen 100 and scraper 160 extended, the piston 96 and snorkel 98 assembly configuration looks similar to the piston and snorkel configuration shown in FIG. 7E. While extending snorkel extension 126 into the mudcake and formation, contaminants and debris tend to gather on screen 100 which can affect the sampling of formation fluids. To clear the debris, which may be mudcake or other contaminants from previous sampling procedures, scraper 160 may be retracted after snorkel assembly 98 has been extended. A downward retract force is applied to scraper tube 150,

preferably by applying a hydraulic fluid force downward on flange 177 of scraper tube 150. The cavity formed by scraper tube 150 and snorkel surface 124 fills with hydraulic fluid as scraper tube 150 moves downward, until scraper tube 150 bottoms out on scraper tube keeper 152. As scraper 160 is drawn within snorkel extension 126 during this process, scraper 160 passes through screen 100 while also frictionally engaging screen 100, thereby agitating and removing debris that has gathered on screen 100. Alternatively, as previously described, debris agitation may be achieved with rotational movement of scraper 160 about its longitudinal axis within screen 100. When scraper tube 150 is fully retracted, apertures 166 radially align with outlet end 135 of screen 100 such that fluid communication is possible between bore 132 of screen 100 and passageway 151 of scraper tube 150. This scraper 160 action that removes debris is preferably performed as part of the formation probe assembly 50 retract sequence, as described below.

To retract formation probe assembly 50, forces, or pressure differentials, may be applied to snorkel 98 and piston 96 in opposite directions relative to the extending forces. Simultaneously, the extending forces may be reduced or ceased to aid in probe retraction. A hydraulic force is applied to snorkel base portion 125 at shoulder 172 to push snorkel assembly 98 down until flange 153 of scraper tube keeper 152 sits on retainer ring 159, thereby fully retracting snorkel assembly 98. Concurrently, a hydraulic force is applied downward on piston base portion 118 at shoulder 170 until base portion 118 bottoms out on stem base portion 105, thereby fully retracting formation probe assembly 50. When piston 96 contacts stem base portion 105, probe retract switch 176 is triggered as described above, signaling a successful retraction of formation probe assembly 50. Scraper 160 may be extended to its original position at any time during retraction. When the extend pressure on the probe assembly, which provides the retract pressure for the scraper assembly because the probe assembly extend portions are hydraulically coupled to the scraper assembly retract portions, falls below the extend pressure on the scraper assembly, scraper 160 is extended.

Another embodiment of the present invention is shown in FIGS. 7A-7F. Probe collar 202 having flowbore 14a houses telescoping formation probe assembly 200. Probe assembly 200, as compared to formation probe assembly 50, extends to reach a borehole wall that is further displaced from collar 202. Such borehole walls that may be displaced further from collar 12 may be found in washed out portions of a well, irregular holes in the well, wells drilled with hole openers or near bit reamers or large wells drilled with bi-center bits. Telescoping probe assembly 200 is useful in reaching a borehole wall in these types of wells.

Telescoping probe assembly 200 generally includes stem plate 210, stem 212, a generally cylindrical threaded adapter sleeve 220, an outer piston 230 adapted to reciprocate within adapter sleeve 220, a piston 240 adapted to reciprocate within outer piston 230, and a snorkel assembly 260 adapted for reciprocal movement within piston 240. Probe collar 202 includes an aperture 204 for receiving telescoping formation probe assembly 200. Cover plate 206 fits over the top of probe assembly 200 and retains and protects assembly 200 within probe collar 202. Formation probe assembly 200 is configured to extend through aperture 208 in cover plate 206.

Referring first to FIG. 7A, adapter sleeve 220 includes inner end 221 near the bottom 207 of aperture 204. Adapter sleeve 220 is secured within aperture 204 by threaded engagement with collar 202 at segment 209. The outer end

223 of adapter sleeve 220 extends to be substantially flushed with opening 205 of aperture 204 formed in collar 202. Outer end 223 includes flanges 225 for engaging cover plate 206. Adapter sleeve 220 includes cylindrical inner surface 227 having reduced diameter portion 226. A seal 229 is disposed in surface 226.

Referring next to FIG. 7B, stem plate 210 includes a circular base portion 213 with an outer flange 214. Extending from base 213 is a short extension 216. Extending through extension 216 and base 213 is a central passageway 218 for receiving the lower end 215 of stem 212 having central passageway 203. Lower end 215 threadedly engages stem plate passageway 218. Central passageway 218 is in fluid connection with fluid passageway 91 (not shown, but seen schematically in FIG. 9) that connects to fluid passageway 93 (not shown, but seen schematically in FIG. 9) leading to other portions of tool 10, including equalizer valve 60. Stem 212 extends up through the center of probe assembly 200. Disposed about stem 212 is Outer stem 219. Threadedly engaged at the top of outer stem 219 is outer stem capture screw 222 having central bore 224.

Referring again to FIG. 7B, outer piston 230 is slidingly retained within adapter sleeve 220 and generally includes cylindrical outer surface 232 having an increased diameter base portion 234. A seal 235 is disposed in increased diameter portion 234. Outer piston 230 also includes cylindrical inner surface 236 having reduced diameter portions 237, 238 at upper extending portion 233. A seal 239 is disposed in surface 237.

Referring now to FIG. 7C, piston 240 is slidingly retained within outer piston 230 and generally includes cylindrical outer surface 242 having an increased diameter base portion 244. A seal 245 is disposed in increased diameter portion 244. Just below base portion 244, piston 240 rests on capture sleeve 254 which is engaged with base portion 234 of outer piston 230. Retainer ring 256 is engaged at the bottom of capture sleeve 254 and holds the capture sleeve in position. Piston 240 also includes cylindrical inner surface 246 having reduced diameter portion 248. Piston 240 further includes central bore 249 having bore surface 241 and extending through upper extending portion 250.

At the top of extending portion 250 of piston 240 is a seal pad 280. As shown in FIGS. 7A-7F, seal pad 280 may be donut-shaped with a curved outer surface 283 and central aperture 286. However, seal pad 280 may include numerous other geometries as is known in the art, or, for example, as is seen in U.S. patent application Ser. No. 10/440,835 entitled "MWD Formation Tester." Base surface 285 of seal pad 280 may be coupled to a skirt 282. Seal pad 280 may be bonded to skirt 282, or otherwise coupled to skirt 282, such as by molding seal pad 280 onto skirt 282 such that the seal pad material fills grooves or holes in skirt 282, as can be seen in U.S. patent application Ser. No. 10/440,835. Skirt 282 is detachably coupled to extending portion 250 by way of threaded engagement with surface 241 of central bore 249, or other means of engagement, such as a pressure fit with central bore surface 241. Because the seal pad/skirt combination is detachable from extending portion 250, it is easily replaced in the field. Alternatively, seal pad 280 may be coupled directly to extending portion 250 without using a skirt. Other characteristics of seal pad 280, such as seal pad material and the way seal pad 280 functions, are similar to the previously described seal pad 180.

Referring now to FIG. 7D, snorkel 260 includes a base portion 262, a snorkel extension 266, and a central passageway 264 extending through base 262 and extension 266. Base portion 262 includes a cylindrical outer surface 268

and inner surface 269. Extension 266 includes a cylindrical outer surface 263 and inner surface 265. Disposed inside the top of extension 266 is a screen 290, best shown in FIG. 7F. Screen 290 is a generally tubular member having a central bore 292 extending between a fluid inlet end 294 and fluid outlet end 296. Screen 290 further includes a flange 298 adjacent to fluid inlet end 294 and an internally slotted segment 293 having slots 295. Between slotted segment 293 and outlet end 296, screen 290 includes threaded segment 297 for threadedly engaging snorkel extension 266.

Threaded to the bottom of base portion 262 of snorkel 260 is scraper tube keeper 270 having a circular base portion 272 and retaining edge 273, a tubular extension 274 having a central passageway 275 and a central aperture 271 for receiving outer stem 219. Outer stem 219 includes central passageway 243. A retainer ring 277 is radially aligned and engageable with retaining edge 273, which limits the movement of snorkel 260 in the retract direction. After snorkel 260 has been extended, retainer ring 277 is disposed below scraper tube keeper 270 in piston surface 246, as can be seen in FIG. 7E. Scraper tube keeper 270 supports scraper tube 278 when scraper tube 278 is in the retracted position shown in FIG. 7F, and isolates the hydraulic fluid reservoir formed by tubular extension 274 and snorkel surface 269. Scraper tube 278 having central passageway 279 is slidably retained above scraper tube keeper 270 in passageway 264 of snorkel 260. Coupled at the top of scraper tube 278 is scraper 288. Scraper 288 is threadedly engaged with scraper tube 278 at threaded segment 281. Scraper 288 is a generally cylindrical member including scraper plug portion 284, central bore 287 and apertures 289 that are in fluid communication with central bore 287. Scraper 288 is disposed within central bore 292 of screen 290 and is reciprocal between screen inlet end 294 and outlet end 296; alternatively, as previously described, scraper 288 may be rotatable within screen 290. When scraper tube 278 and scraper 288 are in their retracted positions, as shown in FIG. 7F, apertures 289 are in fluid communication with fluid outlet end 296 of screen 290, thereby allowing fluid to pass from screen 290, through scraper bore 287, and into central passageway 279 of scraper tube 278.

Referring back to FIG. 7B, a probe retract switch connector 276 is disposed in aperture 278 of probe collar 202, just beneath inner end 221 of sleeve 220. The details of switch connector 276 are similar to the previously described switch 176, above, with reference to FIGS. 8A-8B. Although not shown, switch and connector 276 are electrically coupled to a contact assembly disposed in stem base portion 213. The contact assembly contacts piston 240 when piston 240 is bottomed out on stem base portion 213 indicating to the tool electronics that probe assembly 200 is fully retracted.

Formation probe assembly 200 is assembled such that outer piston base 234 is permitted to reciprocate along surface 227 of adapter sleeve 220, and outer piston surface 232 is permitted to reciprocate along surface 226. Similarly, piston base portion 244 is permitted to reciprocate along outer piston inner surface 236, and piston surface 242 is permitted to reciprocate along outer piston surface 237. Snorkel base portion 262 is disposed within piston 240 and is adapted for reciprocal movement along surface 248 while retaining edge 273 of scraper tube keeper 270 reciprocates between retainer ring 277 and decreased diameter portion 248. Snorkel extension 266 is adapted for reciprocal movement along piston surface 241. Central passageway 264 of snorkel 260 is axially aligned with stem 212, outer stem 219, scraper tube keeper 270, scraper tube 278, scraper 288 and

with screen 290. Formation probe assembly 200 is reciprocal between a fully retracted position, as shown in FIG. 7A, and a fully extended position, as shown in FIG. 7F. Also, scraper tube 278 is reciprocal between a fully extended position, as shown in FIGS. 7A-7E, and a fully retracted position, as is illustrated in FIG. 7F. When scraper tube 278 is fully retracted, fluid may be communicated between central passageway 203 of stem 212, passageway 243 of outer stem 219, passageway 275 of scraper tube keeper 270, passageway 279 of scraper tube 278, bore 287 of scraper 288, scraper apertures 289, screen 290, and the surrounding environment 15.

With reference to FIGS. 7A-7F, the operation of formation probe assembly 200 will now be described. Formation probe assembly 200 typically begins in the retracted position, as shown in FIG. 7A. Assembly 200 remains retracted when not in use, such as when the drill string is rotating while drilling if assembly 200 is used for an MWD application, or when the wireline testing tool is being lowered into borehole 8 if assembly 200 is used for a wireline testing application. FIG. 7A shows assembly 200 in the fully retracted position, with scraper tube 278 in the extended position.

Upon an appropriate command to probe assembly 200, a force is applied to base portion 234 of outer piston 230, preferably by using hydraulic fluid. Outer piston 230 raises relative to adapter sleeve 220, with outer piston base portion sliding along sleeve surface 227. Retainer ring 256 and capture sleeve 254 force piston 240 upward along with outer piston 230 by pressing on piston base portion 244. As seen in FIG. 7B, snorkel 260 remains seated on stem plate 210 while outer piston 230 and piston 240 begin to rise, until retainer ring 277 contacts retaining edge 273 of scraper tube keeper 270. At this point, the upward hydraulic force continues to be applied to the reciprocal parts of assembly 200, and fluid reservoir 334 enlarges and fills until outer piston base portion 234 seats on adapter sleeve shoulder 332, as shown in FIG. 7C. Then hydraulic fluid is directed into reservoir 336, causing piston 240 and snorkel 260 to extend out, with piston base portion 244 sliding along outer piston surface 236. Finally, piston base portion 244 seats on outer piston shoulder 342, as shown in FIG. 7D. Once again, typically, snorkel 260 and seal pad 280 (FIG. 7C) contact the borehole wall prior to reaching full extension, as previously described. The tool stabilizer, or other such device, will react the probe extension force.

Before reaching the position shown in FIG. 7D, seal pad 280 is preferably engaged with the borehole wall (not shown). To form a seal with seal pad 280, probe assembly 200 will continue to pressurize the reservoirs 334, 336 until the reservoirs reach a maximum pressure. Alternatively, if seal pad 180 comes into contact with the borehole wall before probe assembly 200 is fully extended, probe assembly 200 will continue to apply pressure to seal pad 280 up to the previously mentioned maximum pressure. The maximum pressure applied by probe assembly 200, for example, may be 1,200 p.s.i.

As hydraulic fluid continues to be pumped through reservoirs 334, 336, snorkel 260 slides along surfaces 248, 241 as hydraulic fluid is directed into reservoir 338 and this snorkel extend force increases. This snorkel extending force must overcome the retract force being applied on the retract side of snorkel base portion 262 facing piston shoulder 352. Previously, the retract force, provided by retract accumulator 424 and the retract valves, was greater than the extend force, thereby maintaining snorkel 260 in the retract position. However, the extend force continues to increase until it

overcomes the retract force at, for example, 900 p.s.i. Snorkel base portion **262** finally seats on piston shoulder **352**, as shown in FIG. 7E. Snorkel **260** has extended such that the outer end of snorkel extension **266**, inlet end **294** of screen **290** and the top of scraper **288** extend beyond seal pad surface **283** through seal pad aperture **286**. Scraper tube **278** and scraper **288** are still in the extended position, as seen in FIG. 7E. If seal pad **280** is engaged with the borehole wall, snorkel extension **266**, screen inlet end **294** and the top of scraper **288** pierce the mudcake that has been sealed off, and preferably go through the entire mudcake layer and into formation **9**.

As previously described, extending snorkel extension **266** into the mudcake and formation causes contaminants and debris to gather on screen **290**, which can affect the sampling of formation fluids. Floating scraper **288** is used to clear the debris in a similar fashion to that described with respect to formation probe assembly **50**. A downward force is applied to scraper tube **278**, preferably by applying a hydraulic fluid force downward on flange **372** of scraper tube **278**. The cavity formed by scraper tube **278** and inner snorkel surface **269** fills with hydraulic fluid as scraper tube **278** moves downward, until tube flange **372** seats on scraper tube keeper **270**. As scraper **288** is drawn within snorkel extension **266** during this process, scraper **288** passes through screen **290**, agitating and removing debris that has gathered on screen **290** through frictional engagement between scraper **288** and screen **290**, as previously described. Also previously described was an alternative embodiment including a rotating screen **290**, equally applicable here. When scraper tube **278** is fully retracted, apertures **289** radially align with screen outlet end **296** such that fluid communication is possible between screen bore **292** and passageway **279** of scraper tube **278**. This scraper **288** action that removes debris is preferably performed as part of the formation probe assembly **200** retract sequence, as described below.

To retract probe assembly **200**, forces, or pressure differentials, may be applied to probe assembly **200** in opposite directions relative to the extending forces. Simultaneously, the extending forces may be reduced or ceased to aid in probe retraction. First, and preferably, a pressure differential is applied across flange **372** of scraper tube **278** by increasing the hydraulic fluid pressure on the bottom of flange **372**. This extends scraper tube **278** until scraper **288** is fully extended once again, wiping screen **290** clean as scraper **288** passes through it. Next, a hydraulic force is applied to snorkel base portion **262** at shoulder **352** to push snorkel assembly **260** down until retaining edge **273** of scraper tube keeper **270** sits on retainer ring **277**, thereby fully retracting snorkel assembly **260**. Next, a hydraulic force is applied downward on piston base portion **244** at shoulder **342** until base portion **244** seats on capture sleeve **254** and retainer ring **256** adjacent outer piston base portion **234**. From this position, a hydraulic fluid is inserted at adapter sleeve shoulder **332** onto outer piston base portion **234** to force outer piston **230** downward. Outer piston **230** then seats on bottom **207** of aperture **204**, and the piston **240**/snorkel **260** assembly seats on stem plate **210**, thereby fully retracting probe assembly **200**. When piston **240** contacts stem plate **210**, probe retract switch **276** is triggered as described above, signaling a successful retraction of assembly **200**.

It is noted that formation probe assembly **50** may only extend the outer end of piston extending portion **119** past the outer end of sleeve **94** a distance that is less than the length of piston **96**. The length of piston **96** is defined as the distance between the uppermost end of extending portion **119** and the lowermost end of base portion **118**. In compari-

son, probe assembly **200** may extend the outer end of piston upper portion **250** past the outer end of sleeve **220** a distance that exceeds the length of piston **240**. Therefore, the telescoping feature of probe assembly **200**, i.e., the concentric pistons **230**, **240**, allows seal pad **280** to engage a borehole wall that is significantly further from collar **202** than the length of piston **240**.

Referring now to FIG. **14**, an example of how the probe assemblies may be used to test a formation will be described. The test sequence **700** may begin (box **702**) upon a command to the tool **10** from the surface of the borehole, for example, or from embedded tool software. In a first embodiment, piston **96** and seal pad **180** may be extended (box **704**). In a further embodiment, piston **230** may be extended (box **703**) to provide the telescopic effect previously described. The borehole wall is contacted by seal pad **180** (box **706**). Next, a volume surrounding snorkel **98** is sealed (box **708**). In a further embodiment, seal pad **180** may be filled with a fluid (box **707**), as previously described. Continuing with the sequence **700**, snorkel **98** may be extended (box **710**), and the borehole wall contacted by snorkel **98** (box **712**). Scraper **160** may now be retracted (box **714**), causing agitation and removal of contaminants from snorkel **98**. A formation property may then be measured (box **716**). In a further embodiment, contaminants may be filtered (box **715**), such as by a screen **100**. After measuring a formation property, snorkel **98** is retracted (box **718**), piston **96** and seal pad **180** are retracted (box **720**), and scraper **160** is extended (box **722**). The extension of scraper **160** may also serve to remove contaminants from snorkel **98**. Sequence **700** ends (box **724**) with a formation property having been measured for uses further described herein.

In an alternative embodiment of tool **10**, formation probe assemblies **50**, **200** may be located elsewhere in the tool. Referring now to FIG. **3B**, formation probe assembly **50** may instead be disposed in blade **37** of stabilizer **36**. Equalizer valve **60**, shutoff valve **74** and draw down pistons **70**, **72** may remain in the same position as shown in FIG. **3B**, although it is preferred that they be in closer proximity to formation probe assembly **50**, and therefore may be moved closer to stabilizer **36**. Locating formation probe assemblies **50**, **200** in stabilizer blade **37** allows the assemblies to be placed closer to the borehole wall while still mounted in a robust portion of the tool. Further, the other blades of stabilizer **36** may be used to back up formation probe assemblies **50**, **200** as they extend out and pressure up against the borehole wall.

Even if formation probe assemblies **50**, **200** are not disposed in stabilizer **36**, the blades of stabilizer **36** are preferably used to back up the extending formation probe assemblies **50**, **200**. To provide a sufficient sealing force for the probe seal pad, a reactive force must be applied to the tool to counter the force of the extending probe. Alternatively, if a stabilizer is not used, centralizing pistons such as those illustrated and described in U.S. patent application Ser. No. 10/440,593, filed May 19, 2003 and entitled "Method and Apparatus for MWD Formation Testing," hereby incorporated by reference for all purposes, may be used.

With respect to any of the probe assembly embodiments described above, a probe assembly position indicator may be included in the probe assembly to measure the distance that the probe assembly has extended from its fully retracted position. Numerous sensors may be used to detect the position of the probe assembly as it extends. In one embodiment, the probe assembly position indicator may be a measure of the volume of hydraulic fluid used to extend the probe assembly. If the probe assembly is configured to use

hydraulic fluid and pressure differentials to extend, as is described in the embodiments above, the volume of fluid pumped into the probe assembly may be measured. With known diameters for the adapter sleeves and pistons, the distance that the pistons have extended may be calculated using the volume of fluid that has been pumped into the probe assembly. To make this measurement more accurate, certain characteristics of the probe assembly may be accounted for, such as seal pad compression as it compresses against the borehole wall.

In another embodiment of the probe assembly position indicator, an optical or acoustic sensor may be disposed in the probe assembly, such as in an aperture formed in the piston surface **141** of formation probe assembly **50**, or piston surface **242** of probe assembly **200**. The optical or acoustic sensor may measure the distance the piston moves from a known reference point, such as the piston position when the probe assembly is fully retracted. Such devices are well known to one skilled in the art.

In yet another embodiment, a potentiometer, resistance-measuring device or other such device well known to one skilled in the art may be used to detect movement of the reciprocating portions of the probe assemblies through electrical means. The potentiometer or resistance-measuring device may measure voltage or resistance, and such information can be used to calculate distance.

The distance measurement gathered from the probe position indicator may be used for numerous purposes. For example, the borehole caliper may be calculated using this measurement, thereby obtaining an accurate measurement of the borehole diameter. Alternatively, multiple probes may be spaced radially around the drill string or wireline instrument, and measurements may be taken with the multiple probes to obtain borehole diameter and shape. Having an accurate borehole caliper measurement allows the driller to know where borehole breakout or collapse may be occurring. The caliper measurement may also be used to help correct formation evaluation sensors. For example, resistivity measurements are affected by borehole size. Neutron corrections applied to a neutron tool are also affected, as well as density corrections applied to a density tool. Other sensor tools may also be affected. An accurate borehole caliper measurement assists in correcting these tools, as well as any other drilling, production and completion process that requires borehole size characteristics, such as cementing.

In another embodiment, the probe position indicator may be used to correct for probe flow line volume changes. Flow lines, such as flow lines **91**, **93** in FIGS. **6A**, **6B** and **9**, are susceptible to volume changes as the probe seal pad compresses and decompresses. Particularly, when the seal pad is engaged with the borehole wall and a formation test is in progress, the pressure from drawing down the formation fluids causes the seal pad to compress and the flow line volume to increase. The flow line volume is used in several formation calculations, such as mobility; permeability may then be calculated using formation fluid viscosity and density. To correct for this volume change and obtain an accurate flow line volume measurement, probe positioning may be used. Further, although the full flow line volume is known, if the probe does not fully extend before engaging the borehole wall, only a portion of the flow line volume is used and that quantity may not be known. Therefore, the probe position may be used to correct for the portion of the flow line volume that is not being used.

The embodiments of the position indicator described above may also be applied to the draw down piston assemblies, described in more detail below, for knowing where in

the cylinder the draw down piston is located, and how the piston is moving. Volume and diameter parameters of the cylinder may be used to calculate the distance the piston has moved. With a known radius r of the cylinder and a known volume V of hydraulic fluid pumped into the cylinder from either side of the piston, the distance d the piston has moved may be calculated from the equation $V = \pi(r^2)(d)$. Alternatively, sensors may be used as described above, such as optimal sensors, acoustic sensors, potentiometers, or other resistance-measuring devices. Further, the steadiness of the draw down may be obtained from the position indicator. The rate may be calculated from the distance measured over a given time period, and the steadiness of the rate may be used to correct other measurements.

For example, to gain a better understanding of the formation's permeability or the bubble point of the formation fluids, a reference pressure may be chosen to draw down to, and then the distance the draw down piston moved before that reference pressure was reached may be measured by the draw down piston position indicator. If the bubble point is reached, the distance the piston moved may be recorded and sent to the surface, or to the software in the tool, so that the piston may be commanded to move less and thereby avoid the bubble point.

Sensors intended for other purposes may also be disposed in the probe assemblies. For example, a temperature sensor, known to one skilled in the art, may be disposed on the probe assembly for taking annulus or formation temperature. In one embodiment, the temperature sensor may be placed in the snorkel extensions **126**, **266**. In the probe assembly retracted position, the sensor would be adjacent the annulus environment, and the annulus temperature could be taken. In the probe assembly extended position, the sensor would be adjacent the formation, allowing for a formation temperature measurement. Such temperature measurements could be used for a variety of reasons, such as production or completion computations, or evaluation calculations such as permeability and resistivity. These sensors may also be placed adjacent the probe assemblies, such as in the stabilizer blades or centralizing pistons.

Referring back to FIGS. **3B** and **5**, it can be seen that probe collar **12** also houses draw down piston assemblies **70**, **72** and draw down shutoff valve assembly **74**. Referring now to FIG. **11**, draw down piston assembly **70** generally includes annular seal **502**, piston **506**, plunger **510** and endcap **508**. Piston **506** is slidingly received in cylinder **504** and plunger **510**, which is integral with and extends from piston **506**, is slidingly received in cylinder **514**. In FIG. **11**, piston **506** is in its drawn down position, but is typically biased to its uppermost or shouldered position at shoulder **516**. A bias spring (not shown) biases piston **506** to the shouldered position, and is disposed in lower cylinder portion **504b** between piston **506** and endcap **508**. Separate hydraulic lines (not shown) interconnect with cylinder **504** above and below piston **506** in portions **504a**, **504b** to move piston **506** either up or down within cylinder **504** as described more fully below. Plunger **510** is slidingly disposed in cylinder **514** coaxial with cylinder **504**. Cylinder **512** is the upper portion of cylinder **514** that is in fluid communication with the longitudinal passageway **93** (seen schematically in FIG. **9**) that interconnects with draw down shutoff valve assembly **74**, draw down piston **72**, formation probe assembly **50**, **200** and equalizer valve **60**. Cylinder **512** is flooded with drilling fluid via its interconnection with passageway **93**. Cylinder **514** is filled with hydraulic fluid beneath seal **513** via its interconnection with hydraulic circuit **400**.

Endcap **508** houses a contact switch (not shown) having a contact that faces toward piston **506**. A wire **515** is coupled to the contact switch. A plunger **511** is disposed in piston **506**. When drawdown of piston assembly **70** is complete, as shown in FIG. **11**, piston **506** actuates the contact switch by causing plunger **511** to engage the contact of the contact switch, which causes wire **515** to couple to system ground via the contact switch to plunger **511** to piston **506** to endcap **508** which is in communication with system ground (not shown).

Referring to FIG. **12**, a second draw down piston assembly **72** is shown. Draw down piston **72** is similar to piston **70**, with the most notable difference being that the draw down volume is greater and the assembly does not include a bias spring. Draw down piston assembly **72** generally includes annular seal **532**, piston **536**, plunger **540** and endcap **538**. Piston **536** is slidingly received in cylinder **534** and plunger **540**, which is integral with and extends from piston **536**, is slidingly received in cylinder **544**. Plunger **540** and cylinder **544** have greater diameters than the corresponding portions of piston **70**. In FIG. **12**, piston **536** is in its drawn down position, but is typically maintained at its uppermost or shouldered position at shoulder **546** by hydraulic force. Separate hydraulic lines (not shown) interconnect with cylinder **534** above and below piston **536** in portions **534a**, **534b** to move piston **536** either up or down within cylinder **534** as described more fully below. Plunger **540** is slidingly disposed in cylinder **544** coaxial with cylinder **534**. Cylinder **542** is the upper portion of cylinder **544** that is in fluid communication with the longitudinal passageway **93** (seen schematically in FIG. **9**) that interconnects with draw down shutoff valve assembly **74**, draw down piston **70**, formation probe assembly **50**, **200** and equalizer valve **60**. Cylinder **542** is flooded with drilling fluid via its interconnection with passageway **93**. Cylinder **544** is filled with hydraulic fluid beneath seal **543** via its interconnection with hydraulic circuit **400**.

Endcap **538** houses a contact switch **548** having a contact **550** that faces toward piston **536**. A wire **545** is coupled to contact switch **548**. A plunger **541** is disposed in piston **536**. When drawdown of piston assembly **72** is complete, as shown in FIG. **12**, piston **536** actuates contact switch **548** by causing plunger **541** to engage contact **550**, which causes wire **545** to couple to system ground via contact switch **548** to plunger **541** to piston **536** to endcap **538** which is in communication with system ground (not shown).

It will be understood that the draw down pistons may vary in size such that their volumes vary. The pistons may also be configured to draw down at varying pressures. The embodiment just described includes two draw down piston assemblies, but the formation tester tool may include more or less than two.

The hydraulic circuit **400** used to operate formation probe assemblies **50**, **200**, equalizer valve **60** and draw down pistons **70**, **72** is shown in FIG. **9**. A microprocessor-based controller **402** is electrically coupled to all of the controlled elements in the hydraulic circuit **400** illustrated in FIG. **9**, although the electrical connections to such elements are conventional and are not illustrated other than schematically. Controller **402** is located in electronics module **20**, shown in FIG. **2A**, although it could be housed elsewhere in tool **10** or bottom hole assembly **6**. Controller **402** detects the control signals transmitted from a master controller **401** housed in the MWD sub **13** of the bottom hole assembly **6** which, in turn, receives instructions transmitted from the

surface via mud pulse telemetry, or any of various other conventional means for transmitting signals to downhole tools.

When controller **402** receives a command to initiate formation testing, the drill string has stopped rotating if tool **10** is disposed on a drill sting. As shown in FIG. **9**, motor **404** is coupled to pump **406** which draws hydraulic fluid out of hydraulic reservoir **408** through a serviceable filter **410**. As will be understood, the pump **406** directs hydraulic fluid into hydraulic circuit **400** that includes formation probe assembly **50**, **200** (either can be used interchangeably), equalizer valve **60**, draw down pistons **70**, **72** and solenoid valves **412**, **414**, **416**, **418**, **420**, **422**. It will be understood that although the description below will reference only formation probe assembly **50**, the hydraulic circuit described may be used to operate formation probe assembly **50** or probe assembly **200**.

The operation of formation tester **10** is best understood with reference to FIG. **9** in conjunction with FIGS. **6A-6B**, **7A-F**, **11** and **12**. In response to an electrical control signal, controller **402** energizes retract solenoid valve **412** and valve **414**, and starts motor **404**. Pump **406** then begins to pressurize hydraulic circuit **400** and, more particularly, charges probe retract accumulator **424**. The act of charging accumulator **424** also ensures that the formation probe assembly **50** is retracted, the equalizer valve **60** is open and that draw down pistons **70**, **72** are in their initial shouldered position as described with reference to FIGS. **11** and **12**. When the pressure in system **400** reaches a predetermined value, such as 1800 p.s.i. as sensed by pressure transducer **426a**, controller **402** (which continuously monitors pressure in the system) energizes extend solenoid valve **416** which causes formation probe assembly **50** to begin to extend toward the borehole wall **16**. Concurrently, check valve **428** and relief valve **429** seal the probe retract accumulator **424** at a pressure charge of between approximately 500 to 1250 p.s.i. Solenoid valve **412** is still energized.

Formation probe assembly **50** extends, as previously described, from the position shown in FIG. **6A** to a position before full extension as shown in FIG. **6B** (except with snorkel still retracted), where seal pad **180** engages the mud cake **49** on borehole wall **16**. At this point, retract solenoid valve **412** is de-energized, thereby allowing snorkel **98** to be extended and scraper **160** to be retracted. With hydraulic pressure continuing to be supplied to the extend side of piston **96** and snorkel **98** for formation probe assembly **50**, the snorkel may then penetrate the mud cake and the scraper retracted, as shown in FIG. **6B** (and FIGS. **7E-7F** for assembly **200**). The outward extensions of pistons **96** and snorkel **98** continue until seal pad **180** engages the borehole wall **16**, as previously described with regard to formation probe assembly **50**. This combined motion continues until the pressure pushing against the extend side of piston **96** and snorkel **98** reaches a pre-determined magnitude, for example 1,200 p.s.i., controlled by relief valve **417**, causing seal pad **180** to be squeezed. At this point, a second stage of expansion takes place with snorkel **98** then moving within the cylinders **120** in piston **96** to penetrate the mud cake **49** on the borehole wall **16** and to receive formation fluids or take other measurements.

De-energizing solenoid valve **412** also closes equalizer valve **60**, thereby isolating fluid passageway **93** from the annulus. In this manner, valve **412** ensures that valve **60** closes only after the seal pad **140** has entered contact with mud cake **49** which lines borehole wall **16**. Passageway **93**, now closed to the annulus **15**, is in fluid communication with

cylinders **512**, **542** at the upper ends of cylinders **514**, **544** in draw down piston assemblies **70**, **72**, best shown in FIGS. **11** and **12**.

With extend solenoid valve **416** still energized, and the hydraulic circuit **400** at approximately 1,200 p.s.i., probe extend accumulator **430** has been charged and controller **402** energizes solenoid valve **414**. Energizing valve **414** closes off the extend section of the hydraulic circuit, thereby maintaining the extend section at approximately 1,200 p.s.i. and allowing drawdown to begin. With valve **414** energized, pressure can be added to the draw down circuit, which generally includes draw down accumulator **432**, solenoid valves **418**, **420**, **422** and draw down piston assemblies **70**, **72**.

Controller **402** now energizes solenoid valve **420** which permits pressurized fluid to enter portion **504a** of cylinder **504** causing draw down piston **70** to retract. When that occurs, plunger **510** moves within cylinder **514** such that the volume of fluid passageway **93** increases by the volume of the area of the plunger **510** times the length of its stroke along cylinder **514**. The volume of cylinder **512** is increased by this movement, thereby increasing the volume of fluid in passageway **93**. Preferably, these elements are sized such that the volume of fluid passageway **93** is increased by preferably 30 cc maximum as a result of piston **70** being retracted.

If draw down piston **70** is to be stopped due to, for example, the need for only a partial draw down or an unsuccessful partial draw down, controller **402** may energize solenoid valve **418** to pressurize the draw down shutoff valve assembly **74**. Pressurizing valve assembly **74** causes draw down piston **70** to cease drawing down formation fluids. Now, valve assembly **74** and draw down piston **70** have been pressured up to approximately 1,800 p.s.i. This ensures that shutoff valve assembly **74** holds draw down piston **70** in its drawn down, or partially drawn down, position such that the drawn formation fluids are retained and not inadvertently expelled.

When it is desired to continue drawing down with draw down piston **70**, solenoid valve **418** can be de-energized, thereby turning shutoff valve **74** off. Draw down with draw down piston **70** then commences until the volume of cylinder **514** filled. The draw down of draw down piston **70** may continue to be interrupted using valves **418** and **74**. Such interruptions may be necessary to change draw down parameters, such as draw down rate and volume.

Controller **402** may be used to command draw down piston **70** to draw down fluids at differing rates and volumes. For example, draw down piston **70** may be commanded to draw down fluids at 1 cc per second for 10 cc and then wait 5 minutes. If the results of this test are unsatisfactory, a downlink signal may be sent using mud pulse telemetry, or another form of downhole communication, programming controller **402** to command piston **70** to now draw down fluids at 2 cc per second for 20 cc and then wait 10 minutes, for example. The first test may be interrupted, parameters changed and the test may be restarted with the new parameters that have been sent from the surface to the tool. These parameter changes may be made while formation probe assembly **50** is extended.

While draw down piston **70** is stopped, controller **402** may energize solenoid valve **422** which permits pressurized fluid to enter portion **534a** of cylinder **534** causing draw down piston **72** to retract. When that occurs, plunger **540** moves within cylinder **534** such that the volume of fluid passageway **93** increases by the volume of the area of the plunger **540** times the length of its stroke along cylinder **544**.

The volume of cylinder **542** is increased by this movement, thereby increasing the volume of fluid in passageway **93**. Preferably, these elements are sized such that the volume of fluid passageway **93** is increased by 50 cc as a result of piston **72** being retracted. Preferably, draw down piston **72** does not have the stop and start feature of piston **70**, and is able to draw down more fluids at a faster rate. Thus, draw down piston **72** may be configured to draw down fluids at rates of 3.8 or 7.7 cc per second, for example. However, it should be understood that either piston **70**, **72** may be different sizes, and piston **72** may also be configured to have the stop and start feature via the shutoff valve assembly. Thus, hydraulic circuit **400** may be configured to operate multiple pistons **70** and/or multiple pistons **72**. Also, pistons **70**, **72** may be operated in any order.

The ability to control draw down pistons **70**, **72** as described above also allows the operator to purge fluids in the draw down piston assemblies and probe flow lines. For example, if a pre-test volume of fluid has been drawn into the probe, it may be purged by actuating the draw down pistons in the opposite directions. This may be useful for cleaning out any accumulated debris in the flow lines and probe assembly.

Maintaining clean flow lines is important to protecting instruments in the testing tool, and to maintaining the integrity of the formation tests by purging old fluids left in the flow lines. Thus, in another embodiment for keeping the flow lines clean, a mechanical filter may be placed in the flow lines, such as anywhere along flow lines **91**, **93** in FIGS. **6A**, **6B** and **9**. Alternatively, the flow lines may be purged by opening equalizer valve **60**, pumping out fluids present in the flow lines, then closing equalizer valve **60** in preparation of another draw down sequence.

As draw down piston **70** is actuated, 30 cc of formation fluid will thus be drawn through central passageway **127** of snorkel **98** and through screen **100**. The movement of draw down piston **70** within its cylinder **504** lowers the pressure in closed passageway **93** to a pressure below the formation pressure, such that formation fluid is drawn through screen **100** and into apertures **166**, through snorkel **98**, then through stem passageway **108** to passageway **91** that is in fluid communication with passageway **93** and part of the same closed fluid system. In total, fluid chambers **93** (which include the volume of various interconnected fluid passageways, including passageways in formation probe assembly **50**, passageways **91**, **93**, the passageways interconnecting **93** with draw down pistons **70**, **72** and draw down shutoff valve **74**) preferably has a volume of approximately 63 cc. If draw down piston **72** is also activated, this volume should increase approximately 30 cc, up to approximately 90 cc total. Drilling mud in annulus **15** is not drawn into snorkel **98** because seal pad **180** seals against the mud cake. Snorkel **98** serves as a conduit through which the formation fluid may pass and the pressure of the formation fluid may be measured in passageway **93** while seal pad **180** serves as a seal to prevent annular fluids from entering the snorkel **98** and invalidating the formation pressure measurement.

Referring momentarily to FIG. **6B**, formation fluid is drawn first into the central bore **132** of screen **100**. It then passes through slots **134** in screen slotted segment **133** such that particles in the fluid are filtered from the flow and are not drawn into passageway **93**. The formation fluid then passes between the outer surface of screen **100** and the inner surface of snorkel extension **126** where it next passes through outlet end **135**, apertures **166** in scraper **160**, scraper tube **150** and into the central passageway **108** of stem **92**.

Screen 100 (and screen 290 of assembly 200) may be optimized for particular applications. For example, if prior knowledge of the formation is obtained, then the screen can be tailored to the type of rock or sediment that is present in the formation. One type of adjustable screen is a gravel-packed screen, which may be used instead of or in conjunction with the slotted screen 100. Generally, a gravel-packed screen is two longitudinal, cylindrical screens of different diameters. The screens are disposed concentrically and the annulus is filled with gravel pack sieve, or a known sand size.

Despite the type of formation encountered, the gravel pack may be tailored to have a 10-to-1 ratio of formation sand size to gravel pack size, which is the preferable formation particle size to gravel particle size ratio. With this ratio, it is expected that the gravel pack screen will have the ability to screen formation particles up to $1/10^{th}$ the size of the nominal formation particle diameter size encountered. With this embodiment, the gravel pack sand size can be tailored to the specific intended application.

In yet another embodiment, the screens 100, 290 as they are illustrated in FIGS. 6B, 7F may be optimized by adjusting the size and number of slits required for a particular application. The slits, or slots, are illustrated schematically as internally slotted segment 133 having slots 134 in FIG. 6B, and internally slotted segment 293 having slots 295. The size and number of slits can be tailored to the particular formation expected to be intersected, and the nominal sand particle size of the produced sand. For example, more slits with smaller openings may be used for smaller nominal formation particle size.

In a further embodiment, the above mentioned adjustment of slot size may be accomplished real-time. In the previous embodiment, the slot size is set upon deployment of tool 10 into the borehole. The slot size remains unchanged while tool 10 is deployed. The slot size may be adjusted at the surface of the borehole by replacing screens 100, 290, or by manually adjusting the slot sizes, but may not be adjusted real-time, or while tool 10 is deployed downhole. In the current embodiment, detection of the type of formation actually intersected may be achieved via the various apparatus and methods disclosed herein. If the detected formation value, such as particle size, differs from a predetermined value, the slot size may be adjusted without tripping tool 10 out of the borehole. A command may be given from the surface of the borehole, or from tool 10, and slot size may be adjusted by moving two concentrically disposed slotted cylindrical members relative to each other, for example, or by adjusting shutter mechanisms adjacent the slots.

Referring again to FIG. 9, with seal pad 180 sealed against the borehole wall, check valve 434 maintains the desired pressure acting against piston 96 and snorkel 98 to maintain the proper seal of seal pad 180. Additionally, because probe seal accumulator 430 is fully charged, should tool 10 move during drawdown, additional hydraulic fluid volume may be supplied to piston 96 and snorkel 98 to ensure that seal pad 180 remains tightly sealed against the borehole wall. In addition, should the borehole wall 16 move in the vicinity of seal pad 180, the probe seal accumulator 430 will supply additional hydraulic fluid volume to piston 96 and snorkel 98 to ensure that seal pad 180 remains tightly sealed against the borehole wall 16. Without accumulator 430 in circuit 400, movement of the tool 10 or borehole wall 16, and thus of formation probe assembly 50, could result in a loss of seal at seal pad 180 and a failure of the formation test.

With the drawdown pistons 70, 72 in their fully, or partially, retracted positions and anywhere from one to 90 cc

of formation fluid drawn into closed system 93, the pressure will stabilize enabling pressure transducers 426b, 426c to sense and measure formation fluid pressure. The measured pressure is transmitted to the controller 402 in the electronic section where the information is stored in memory and, alternatively or additionally, is communicated to the master controller 401 in the MWD tool 13 below formation tester 10 where it can be transmitted to the surface via mud pulse telemetry or by any other conventional telemetry means.

When drawdown is completed, pistons 70, 72 actuate their contact switches previously described. When the contact switch 550, for example, is actuated controller 402 responds by shutting down motor 404 and pump 406 for energy conservation. Check valve 436 traps the hydraulic pressure and maintains pistons 70, 72 in their retracted positions. In the event of any leakage of hydraulic fluid that might allow pistons 70, 72 to begin to move toward their original shouldered positions, drawdown accumulator 432 will provide the necessary fluid volume to compensate for any such leakage and thereby maintain sufficient force to retain pistons 70, 72 in their retracted positions.

During this interval, controller 402 continuously monitors the pressure in fluid passageway 93 via pressure transducers 426b, 426c. When the measured pressure stabilizes, or after a predetermined time interval, controller 402 de-energizes extend solenoid valve 416. When this occurs, pressure is removed from the close side of equalizer valve 60 and from the extend side of probe piston 96. Equalizer valve 60 will return to its normally open state and probe retract accumulator 424 will cause piston 96 and snorkel 98 to retract, such that seal pad 180 becomes disengaged with the borehole wall. Thereafter, controller 402 again powers motor 404 to drive pump 406 and again energizes solenoid valve 412. This step ensures that piston 96 and snorkel 98 have fully retracted and that the equalizer valve 60 is opened. Given this arrangement, the formation tool has a redundant probe retract mechanism. Active retract force is provided by the pump 406. A passive retract force is supplied by probe retract accumulator 424 that is capable of retracting the probe even in the event that power is lost. It is preferred that accumulator 424 be charged at the surface before being employed downhole to provide pressure to retain the piston and snorkel in housing 12.

It will be understood that the equalizer valve 60 may be opened in a similar manner at other times during probe engagement with the borehole wall. If the probe seal pad is in danger of becoming stuck on the borehole wall, the suction may be broken by opening equalizer valve 60 as described above.

After a predetermined pressure, for example 1800 p.s.i., is sensed by pressure transducer 426a and communicated to controller 402 (indicating that the equalizer valve is open and that the piston and snorkel are fully retracted), controller 402 de-energizes solenoid valves 418, 420, 422 to remove pressure from sides 504a, 534a of drawdown pistons 70, 72, respectively. With solenoid valve 412 remaining energized, positive pressure is applied to sides 504b, 534b of drawdown pistons 70, 72 to ensure that pistons 70, 72 are returned to their original positions. Controller 402 monitors the pressure via pressure transducer 426a and when a predetermined pressure is reached, controller 402 determines that pistons 70, 72 are fully returned and it shuts off motor 404 and pump 406 and de-energizes solenoid valve 412. With all solenoid valves returned to their original positions and with motor 404 off, tool 10 is back in its original condition.

The hydraulic circuit 400, as described and illustrated in FIG. 9, may also act as a regenerative circuit while extend-

ing the probe assembly. With both retract valve **412** and extend valve **416** energized or actuated, as described above, and the difference in areas between the smaller area on the retract side of the probe piston, such as piston **96** or piston **240**, and the larger area on the extend side of the piston, there is a net effect of extending the probe assembly. As the piston continues to extend with retract valve still open, there is a back flow of hydraulic fluid through retract valve **412** due to the lack of a check valve behind retract valve **412**. This relatively unimpeded back flow path leads into the pressurized hydraulic fluid flowing into extend valve **416**, adding to the pressure on the extend side of the circuit and increasing the rate at which the probe may extend.

During extension of the probe assembly, using hydraulic circuit **400**, it can be seen that the total volume of hydraulic fluid required to be displaced by pump **406**, and hence the number of revolutions of motor **404**, is reduced compared to a non-regenerative circuit. The regenerative nature of circuit **400** also allows the moveable wiper or scraper, such as scraper **160**, to remain extended during extension of the probe assembly, especially as the snorkel assembly is penetrating the mudcake and formation and there is an extra force pushing back on the moveable scraper. As can be seen in FIGS. **6A**, **6B** and **7A-7F**, the area of the extend side of the scraper assembly, for example, the bottom of flange **372** of scraper tube **278** in FIG. **7F**, is greater than the area of the retract side, or the upper side of flange **372**. Thus, with both valves **412** and **416** actuated, the same hydraulic pressure acts on different areas, causing the wiper element to extend and the pressurized fluid to regenerate on the extend side of the scraper tube **278**, as previously described.

Further, as mentioned before, the regeneration of pressure in circuit **400** allows faster extension of the probe assembly. In addition, the regenerated pressure assists with control of equalizer valve actuation.

A hydraulic reservoir accumulator assembly **600** is disposed in probe collar **12** as shown in FIG. **10I**. Reservoir accumulator assembly **600** maintains a pressure above the annulus or surrounding environment pressure in the complete tool **10** hydraulic system. This condition in the hydraulic system compensates for pressure and temperature changes in the tool. Also, the pressure provided from assembly **600** causes pump **406** (FIG. **9**) to begin operating from the annulus pressure, thereby reducing the work load that would be required from starting pump **406** at atmospheric pressure. Thus, accumulator assembly **600** may be used to communicate annulus pressure into the tool's hydraulic system. As will be seen below, assembly **600** is self contained and easily field replaceable.

Assembly **600** generally includes a body **602** having a top surface **632**, bottom surface **634** (FIG. **10C**) and endcap **604** at end **606**, several locking wings **608** and drilling fluid apertures **618**, **620** at end **622**. Top surface **632** includes additional fluid apertures **628**, **630** covered by a screen **639** as illustrated in FIG. **10F**. Screen **639** is held in place by retaining ring **637**, and prevents large particles in the drilling fluid from entering the cylinders and interfering with the reciprocation of the pistons. Endcap **604** includes a pressure plug **638** for connecting assembly **600** to probe collar **12**, which helps to lock assembly **600** into place as illustrated in FIG. **10H**. Endcap **604** also includes hydraulic fluid check valves **640**, **642** for fluid communication with the tool hydraulic circuit, and for checking fluid into assembly **600** and the tool hydraulic system when assembly **600** is removed from collar **12**.

Referring briefly to FIG. **10F**, it can be seen that the inside of assembly **600** is split into two cylinders **626**, **646**. FIG.

10C illustrates cylinder **626** retaining a piston **636** which separates cylinder **626** into hydraulic fluid portion **626a** and drilling fluid portion **626b**. Piston **636** is reciprocal between the position shown in FIG. **10C** and the position of piston **656** shown in FIG. **10D**. Spring **624** is retained in cylinder portion **626b** between piston **636** and end **622**. Spring **624** extends past piston end **636b** around piston **636** and seats on increased piston diameter portion **633**. Increased diameter portion **633** is similar to increased diameter portion **653** of piston **656**, illustrated in FIG. **10G**. At end **622**, aperture **620** allows drilling fluids to enter cylinder portion **626b** and exert the surrounding annulus pressure on side **636b** of piston **636**. Because spring **624** also exerts a force on side **636b**, the pressure of hydraulic fluid in cylinder portion **626a** is greater than the annulus pressure. The pressure of the hydraulic fluid in cylinder portion **626a** is the annulus pressure plus the pressure added by spring **624**. Spring **624** may exert, for example, a pressure of approximately 60-80 p.s.i.

Cylinder **646** of FIG. **10D** operates in a similar fashion to cylinder **626**. Drilling fluid enters cylinder portion **646b** through aperture **622**, thereby exerting the annulus pressure on side **656b** of piston **656**. Spring **644** then increases the pressure on piston **656**, causing the hydraulic fluid in cylinder **646a**, and therefore the hydraulic fluid in the tool hydraulic system, to be greater than the annulus pressure. Spring **644** is shown in the fully compressed position in FIG. **10D**.

Referring now to FIG. **10G**, enlarged piston end **656a** includes seal **659** for sealing the drilling mud from the system hydraulic fluid, and scraper **661** for cleaning the cylinder bore **646** as piston **656** reciprocates. Spring **644** seats on increased diameter portion **653**. Piston end **636a** is similar to piston end **656a** illustrated in FIG. **10G**.

Preferably, pistons **636**, **656** reciprocate independently of each other while maintaining the pressure in the hydraulic system of the tool. Also, both pistons communicate with the entire tool hydraulic system.

Referring now to FIG. **10H**, accumulator assembly **600** is illustrated placed into position in collar **12**, but not locked down. To engage assembly **600** with cavity **601** in collar **12**, assembly **600** is disposed above cavity **601** and locking wings **608** (FIG. **10A**) are aligned with recesses **664**. Recesses **664** are L-shaped (not shown) with the bottom portions of the L extending toward endcap **604** and end **603** of cavity **601**. Assembly **600** is lowered into cavity **601** with locking wings **608** sliding down through recesses **664** until assembly **600** seats at the bottom of cavity **601** and top surface **632** is substantially flush with the surface of collar **12**. Assembly **600** is then moved toward cavity end **603** such that locking wings **608** move into the extending bottom portions of recesses **664** and pressure plug **638** (FIG. **10A**) pressure fits into an aperture (not shown) disposed at end **603** of cavity **601**. This forward movement also causes a gap **678** to be formed between cavity end **605** and assembly end **622**.

To lock assembly **600** into place, a wedge **670** is placed into gap **678**. The angled end **622** (illustrated in FIG. **10C**) matingly receives the angled side **676** of wedge **670**. The wedging action of these mating surfaces ensures that assembly **600** is moved fully forward in cavity **601**. Bolts **674** and nuts **672** lock down wedge **670**. Further, L-shaped locking pieces **668** are placed into recesses **664** and bolts **666** are used to lock down wings **608**. The final locked position of assembly **600** is illustrated in FIG. **10I**. Fluid ports **628**, **630** communicate with drilling fluid in annulus **15**. Fluid entering cylinder portions **626b** and **646b** through apertures **618**, **620** is screened by slots in wedge **670** (slots not shown).

Removing accumulator assembly 600 requires a process done in reverse of the process just described. While removing assembly 600, check valves 640, 642 close and maintain oil in the tool hydraulic system. Assembly 600 may then be cleaned and/or replaced. Check valves 640, 642 open again once assembly 600 is locked into position. Hydraulic fluid may then be added to make up for any fluid loss, and preferable fluid is added to the extent that pistons 636, 656 are pushed back to the position illustrated in FIG. 10D.

The uplink and downlink commands used by tool 10 are not limited to mud pulse telemetry. By way of example and not by way of limitation, other telemetry systems may include manual methods, including pump cycles, flow/pressure bands, pipe rotation, or combinations thereof. Other possibilities include electromagnetic (EM), acoustic, and wireline telemetry methods. An advantage to using alternative telemetry methods lies in the fact that mud pulse telemetry (both uplink and downlink) requires pump-on operation but other telemetry systems do not.

The down hole receiver for downlink commands or data from the surface may reside within the formation test tool or within an MWD tool 13 with which it communicates. Likewise, the down hole transmitter for uplink commands or data from down hole may reside within the formation test tool 10 or within an MWD tool 13 with which it communicates. In the preferred embodiment specifically described, the receivers and transmitters are each positioned in MWD tool 13 and the receiver signals are processed, analyzed and sent to a master controller 401 in the MWD tool 13 before being relayed to local controller 402 in formation testing tool 10.

The above discussion is meant to be illustrative of the principles and various embodiments of the present invention. While the preferred embodiment of the invention and its method of use have been shown and described, modifications thereof can be made by one skilled in the art without departing from the spirit and teachings of the invention. The embodiments described herein are exemplary only, and are not limiting. Many variations and modifications of the invention and apparatus and methods disclosed herein are possible and are within the scope of the invention. Accordingly, the scope of protection is not limited by the description set out above, but is only limited by the claims which follow, that scope including all equivalents of the subject matter of the claims.

What is claimed is:

1. A downhole apparatus comprising:
 - a drill collar having an outer surface for interaction with an earth formation;
 - an extendable sample device having a bore and recessed beneath said outer surface in a first position to extend beyond said outer surface to a second position;
 - a first draw down chamber slidably retaining a first draw down piston, said first draw down piston actuatable between a first position and a second position and said first draw down chamber in fluid communication with said extendable sample device;
 - a flow line between said extendable sample device and said first draw down chamber, said bore and said flow line to receive at least formation fluid from the earth formation; and
 - a second draw down chamber slidably retaining a second draw down piston, said second draw down chamber in fluid series with said first draw down chamber and said extendable sample device.
2. The apparatus of claim 1 wherein said first and second draw down chambers have different volumes.

3. The apparatus of claim 1 wherein said first and second draw down pistons are operable independently of each other.

4. A downhole apparatus comprising:

- a drill collar having an outer surface for interaction with an earth formation;
- an extendable sample device having a bore and recessed beneath said outer surface in a first position to extend beyond said outer surface to a second position;
- a draw down chamber slidably retaining a draw down piston, said draw down piston actuatable between a first position and a second position and said draw down chamber in fluid communication with said extendable sample device;
- a flow line between said extendable sample device and said draw down chamber, said bore and said flow line to receive at least formation fluid from the earth formation; and
- a position indicator in communication with said draw down chamber to signal a position of said draw down piston.

5. The apparatus of claim 4 wherein said position indicator is any one of an acoustic sensor, an optical sensor, a potentiometer, a resistance-measuring device, and a contact switch to signal said draw down piston first position.

6. The apparatus of claim 4 further comprising a controller programmed to command said draw down piston to stop at a third position within said draw down chamber between said first and second positions, and to command said draw down piston to be restarted.

7. The apparatus of claim 6 further comprising:

- a solenoid valve;
- a shutoff valve; and
- wherein said controller communicates with said valves to command said draw down piston.

8. The apparatus of claim 4 further comprising a filter disposed in said flow line.

9. The apparatus of claim 4 further comprising:

- a hydraulic circuit in fluid communication with said extendable sample device and said draw down chamber; and
- said hydraulic circuit including an accumulator to communicate fluid with at least one of said extendable sample device and said draw down chamber.

10. The apparatus of claim 9 wherein said accumulator is any one of a retract accumulator, an extend accumulator and a draw down accumulator.

11. The apparatus of claim 9 wherein said hydraulic circuit comprises valves to divert fluid from a retract side of said extendable sample device toward an extend side of said extendable sample device as said extendable sample device is actuated from said first position to said second position.

12. The apparatus of claim 4 further comprising:

- a hydraulic circuit having a fluid pressure; and
- a hydraulic reservoir accumulator, said hydraulic reservoir accumulator in fluid communication with an annulus surrounding said drill collar and said hydraulic circuit such that said reservoir accumulator communicates an annulus fluid pressure to said hydraulic circuit.

13. The apparatus of claim 12 wherein said hydraulic reservoir accumulator further comprises:

- a body having an internal cylinder;
- a piston slidingly retained within said cylinder, wherein a first side of said piston communicates with said hydraulic circuit and a second side of said piston communicates with said annulus;

29

a spring retained within said cylinder between a cylinder end and said second piston side, said spring exerting a pressure on said piston; and

wherein said piston communicates said annulus pressure and said spring pressure to said hydraulic circuit.

14. The apparatus of claim 13 wherein said hydraulic reservoir accumulator body comprises a plurality of locking wings and said recess comprises a plurality of L-shaped slots for receiving said locking wings.

15. The downhole apparatus of claim 12 wherein said drill collar outer surface comprises a recess for receiving said hydraulic reservoir accumulator, and said recess and said hydraulic reservoir accumulator to maintain said hydraulic circuit fluid pressure when said hydraulic reservoir accumulator is removed from said recess.

16. A method of operating a downhole apparatus comprising:

disposing a drill collar in a borehole, the drill collar comprising an extendable sample device, a hydraulic circuit and a draw down piston assembly;

extending a sampling member from the extendable sample device beyond the drill collar;

moving a piston of the draw down piston assembly;

drawing a fluid into the extendable sample device and a flow line connecting the extendable sample device and the draw down piston assembly;

accumulating a fluid pressure in the hydraulic circuit; diverting a hydraulic fluid from a retract side of the sampling member;

directing the fluid to the extend side of the sampling member; and

providing an additional extending force to the extend side of the sampling member.

17. The method of claim 16 further comprising filtering the fluid drawn into the flow line.

18. The method of claim 17 further comprising measuring a property of the fluid drawn into the flow line.

19. The method of claim 16 further comprising:

disposing an equalizer valve in the drill collar, the equalizer valve in fluid communication with the flow line;

30

opening the equalizer valve; and pumping the fluid in the flow line out through the equalizer valve to clean the flow line.

20. The method of claim 16 further comprising indicating a position of the draw down piston at any point during the draw down piston movement.

21. The method of claim 20 wherein indicating a position further comprises calculating a distance the draw down piston has moved using a known volume of fluid for moving the draw down piston and a known radius value of the draw down piston.

22. The method of claim 20 further comprising calculating a rate of draw down piston movement and correcting another downhole measurement.

23. The method of claim 20 wherein the draw down piston may be moved between a first and second position, further comprising:

stopping the draw down piston at a third position; and re-starting movement of the draw down piston.

24. The method of claim 23 wherein the re-starting movement of the draw down piston occurs at a different rate than the moving a draw down piston.

25. The method of claim 23 further comprising: purging a fluid from the extendable sample device; and cleaning debris from the extendable sample device.

26. The method of claim 16 further comprising: using an extend accumulator in the hydraulic circuit to accumulate a fluid pressure; and providing an additional extending force to the extendable sample device.

27. The method of claim 16 further comprising: using a retract accumulator in the hydraulic circuit to accumulate a fluid pressure; and providing a retract force to the extendable sample device.

28. The method of claim 16 further comprising: using a drawdown accumulator in the hydraulic circuit to accumulate a fluid pressure; and providing a force to the draw down piston assembly.

* * * * *